

Appendix C

Legal Basis for Water Reallocations

C.1 Introduction

The aim of this study is to review all legislation pertinent to water resources in the Kingdom, specifically private wells and springs that are used for irrigation, with the objective of identifying the different options available for curtailment or reallocation of water use that are provided for under the Law. The objective for sustainable development of the NGWA water supply system is to reduce over-abstraction of groundwater beyond the safe yield of aquifers, and to transfer some of the water from private use to use in municipal water supply. This review has been prepared by IBLAW under subcontract to CDM, with some editing by CDM. The objective is to identify legal obstacles and consequences of reallocation options. It is intended to provide assistance to the Ministry of Water and Irrigation (MWI) and Water Authority of Jordan (WAJ) in identifying the availability of water reallocation options under Law. This review does not aim at revising and/or identifying technical aspects of allocating alternative water resources.

The study and review of the legislation has encompassed all pertinent legislation with special attention given to the following: the Water Authority Law and its amendments No (18) for the Year 1988; the Groundwater Control Regulation No (85) for the Year 2002; the Civil Code and its amendments No (43) for the Year 1976; the Expropriation Law and its amendments No (12) for the Year 1987; in addition to the judicial precedents available on the subject matter. In addition, several interviews and meetings have been held with officials from MWI and WAJ.

Although the geographical area of interest to this study is the northern governorates of Irbid, Jarash, Ajloun and Mafraq, it was found that the legislation applicable to this area is that applicable to the country as a whole. The findings are described below under the following headings: the legal definitions and ownership of water resources, specifically wells and springs; the authority of WAJ under the existing laws and regulations; and conclusions.

C.2 Water Resources

Article (2) of the Water Authority Law has defined water resources as follows:

Surface and ground water from all sources, including seas, lakes, rivers, springs, rain water, dams, wells, pools, and reservoirs. This word also includes mineral water and hot water.

The WAJ Law has stipulated that the State is the sole owner of the surface and ground water¹ and water cannot be used, exploited or transferred unless according to the Law, and WAJ shall have the sole authority to dispose of such in any manner it deems fit since it is administering a vital public utility, provided that such actions are always targeted towards the public interest and good. Moreover, WAJ is the legal and actual successor of any governmental department, corporation or any public commission or municipality². Pursuant

¹ Article (25/a) of the WAJ Law and Article (3/a) of the Groundwater Control Regulation.

² Article (23) of the WAJ Law. Although it is clear that MWI/WAJ is the authority responsible for water and water resources in the Kingdom; however, there are still active laws that deal with water and water resources that have not been repealed after the

to the provisions of the Law, WAJ has the authority to direct and regulate the construction of public and private wells, investigate water resources, and drill exploratory, reconnaissance and production wells, and license well drilling rigs and drillers³.

For the purposes of this study, special attention is given to wells and springs, and to the entitlements under law for the use of water.

C.2.1 Wells

Article (2) of the Groundwater Control Regulation has defined a “well” as follows:

Any sinkhole or hole made by a machine or special tool used to reach the groundwater layer to extract water to the surface either naturally or by a machine.

In addition to the provisions stipulated in the WAJ Law, the Groundwater Control Regulation⁴ allows regulation of wells. The provisions of the Regulation do not differentiate between wells drilled for irrigation and those drilled for other uses, except for specific licensing conditions and pricing of abstractions. For private wells, the methods of using the groundwater extracted there from, and the quantities thereof shall be determined through regulatory decisions issued by WAJ.⁵ For irrigation wells, the regulatory measures for ensuring safe extraction from any water basin shall be determined by WAJ’s Board in coordination with the Ministry of Agriculture, which defines the arable area of the land from which the water is extracted and the quantities of water needed for its irrigation, in light of the types of crops and the irrigation methods used for this purpose⁶.

Abstraction of water from wells is regulated under a drilling license and an extraction license. The extraction license specifies, *inter alia*, the following⁷:

1. The maximum amount of water permitted to be extracted from the well within a fixed period of time. This has been specified at times in the past, but not at present, as discussed subsequently.
2. The purpose of water use, such as tourism, industry or irrigation.
3. The land plot that will be irrigated by a well licensed for agricultural purposes.
4. The installation, at the expense of the owner of the well, of a water-meter after it has been approved and stamped by WAJ. This condition should be complied with prior to the issuance of the water extraction license.
5. Notification of WAJ within a period not exceeding 48 hours in case of non-function of the water-meter.
6. Refraining from taking any measures that impede the flow of water from the well to the water-meter directly for the measurement thereof.
7. Obligation by the licensee to pay to WAJ on time the prices fixed for the extracted water.

passage of the WAJ Law such as the Law for Regulating Natural Resources Affairs and its amendments No (12) for the Year 1968 and the Municipalities Law and its amendments No (29) for the Year 1955.

² Article (6) of the WAJ Law.

³ Article (6/c) of the WAJ Law.

⁴ Article (25) of the WAJ Law and Article (3) of the Groundwater Control Regulation. This was verified by the Court of Cassation in many decisions, the most recent is decision No 415/1999 dated 30/9/1999.

⁵ Articles (4/b and c) and (7) of the Groundwater Control Regulation.

⁶ Article (4) of the Groundwater Control Regulation.

⁷ Article (29) of the Groundwater Control Regulation.

8. Keeping by the licensee of a register-approved by WAJ where all data relating to the well and extraction process shall be registered regularly in accordance with instructions issued by WAJ.

Every licensee should undertake not to pollute or deplete the water and abide by the conditions of the license, subject to revocation of the license.

Article 17

WAJ's Board may, based on the recommendation of the Secretary General, take the following decision:

- Cancel the drilling or extraction license, if the licensee violates any of the conditions therein, and shut down the well until the breach is rectified.
- Cancel or amend the license conditions if the public interest so requires.

Article 18

The Secretary General may take any of the following measures:

- Backfill any well drilled without a license in pursuance of the provisions of this Regulation.
- Backfill any well whose owner did not abide by the conditions of the license granted thereto.

Moreover, the WAJ Law has dealt explicitly with sanctions for specific violations. Most importantly to the purposes of this review are the following penalties for the following violations:

- Imprisonment for a period not less than (6) months and not exceeding (2) years or a fine not less than (1000) one thousand dinars and not exceeding (5000) five thousand dinars or both penalties, whichever penalty in the court's judgment befits the violation for drilling groundwater wells without a license or in violation of the license granted.
- Imprisonment for a period not less than (1) month and not exceeding (6) months, or a fine not less than (100) one hundred dinars and not exceeding (1000) one thousand dinars for one of the following acts:
 - The illegal usage of water, water resources, related projects or the public sewers, contravening the provisions of this Law, or regulations issued pursuant thereto (which in our case is the Groundwater Control Regulation applicable on wells and springs), including the selling, granting or transporting water, using or utilizing it or committing any act that may cause harm or damage to any of these resources or water related projects, or using the public sewers in a manner that conflicts with the provisions of this Law.
 - Carrying out any act regarding water or wastewater without obtaining the licenses, permits or approvals required under this Law, or carrying out any of these works in violation of the regulations issued pursuant to the Law (which in our case is the

Groundwater Control Regulation applicable on wells and springs).

Initiation of acts to commit any of the violations stipulated under the WAJ Law shall also be subject to punishment. If any person is found guilty of committing any of these acts, the Court shall convict him and make him pay the total of the damages caused by his violation and compel him to eliminate the damage caused and restore the conditions as they existed before committing such acts within the period specified by the Court. If he fails to do so, WAJ shall have the right to carry out the necessary works and repairs and charge the convicted person with the total cost plus 50% of the cost⁸.

Moreover, the Groundwater Regulation has referred the following acts to the sanctions under the WAJ Law⁹:

- If a person was caught performing drilling, deepening, cleaning, maintaining or testing any well or extracting water there from, or operating or possessing a drilling rig in contradiction to the provisions of this Regulation, a restraint report against him should be made, and the drilling rig and other equipment shall be seized. The offender shall be referred to the competent court to inflict upon him the punishment provided for under this Regulation.
- The provisions apply to the owner or possessor of the land where the violation took place. The offender shall bear the costs of the seizure until a decision by the court is made there upon, without affecting the right of WAJ to remove the offence by administrative means in accordance with the WAJ Law.

However, in practice and from our meetings with WAJ officials, we find that WAJ had to take certain measures to deal with the sensitivity of the water issue in Jordan and irrigation wells. Hence, we find that the licenses no longer provide for a maximum amount of extraction, as long as the licensee pays the fees for the extracted water, which are minimal in value¹⁰, although Article (17) of the Groundwater Control Regulation provides for more severe measures. These fees are as follows:

- | | |
|--|--|
| • From zero to 150 thousand cubic meters | free of charge |
| • From 150 to 200 thousand cubic meters | 5 fils per cubic meter. |
| • More than 200 thousand cubic meters | 60 fils per cubic meter. ¹¹ |

From studying the Law and Regulation and reviewing this trend, we find that the lack of a specified upper limit on abstractions might pose a problem with regards to its legality, since the Law and Regulation provide for the requirements of the license and the measures and sanctions provided for violating such and the approach used does not seem in harmony therewith.

Moreover, we find that Article (41) of the Groundwater Control Regulation has allowed - for a specified period of time and for a fee - the continuation of water extraction out of unlicensed wells on the basis of principles approved by the Council of Ministers and if there are economic or social factors justifying such. However, we find that the WAJ Law considers

⁸ Article (30) of the WAJ Law.

⁹ Article (19) of the Groundwater Control Regulation.

¹⁰ Article (38/a/1) of the Groundwater Control Regulation.

¹¹ The fees are restated in the license.

such an act as a crime that is subject to punishment; and whereas the Regulation must conform with the provisions of the Law since the Law is the higher legal instrument, the Regulation should not set provisions conflicting with the provisions of the Law. And in cases of conflict, the provisions of the Law shall supersede.

In addition to what is stated above and since WAJ's employees are public servants, they are compelled, according to Article (25) of the Law for the Criminal Proceedings Rules, to refer any person committing a crime to the relevant authorities. Accordingly, again we find a discrepancy here between the provisions of the laws and the provisions of the Regulation.

C.2.2 Springs

Article (2) of the Groundwater Control Regulation has defined a "spring" as:

A water source surfacing from underground due to geological and hydrological factors either incessantly or intermittently.

Under the legislation, there are no specific provisions that deal with springs per se, except in Article (26) of the Groundwater Control Regulation, which stipulates that it is hereby prohibited to issue a license to drill a new or a substitute well, or to deepen an existing well in the vicinity of springs, unless the drilling site is not less than three km away from the nearest spring, provided that the applicant submits a written undertaking that the extracted water will not have an effect in any way on the average output of the spring. If it is proven that the average output of the spring has been affected, or its natural flow has been halted, then the license shall be cancelled by a decision of WAJ's Board on the submission of the Secretary General who shall take the necessary measures to backfill the said well.

C.2.3 Entitlements under Law for Water Use from Springs

Springs are water resources that are not confined to one area, and flow into watercourses which people use to irrigate their land. If the spring has a permanent or temporary watercourse and people are lawfully using this watercourse to irrigate their lands, these landowners are entitled to receive compensation for the harm inflicted unto their land as a result of them being deprived of this right. This right is known as "the right of irrigation".

Article (1292) of the Civil Code has defined the right of irrigation to be the use of a water transfer to irrigate land or plantings. It is important to differentiate here between whether the subject matter of a dispute arising from compensation is based on the right of irrigation itself, or on the harm resulting from depriving the land and its owner from such right. In the first case, resolving such dispute is the authority of the Amicable Court according to the Amicable Courts Law, which looks into the infringements on the right of irrigation and the disputes resulting there from. Whereas in the second case, the competent court is the Court of First Instance.

In either case, the right of irrigation, although established under the Civil Code, is bound by the laws and regulations. The right of irrigation for the land on which settlement has occurred should be registered in the water rights' register at the Lands and Survey Department, since this register is considered the definitive evidence that proves the existence of such right. However, if the land is not subject to settlement or excluded there from, or the right of irrigation is not settled through the Lands Department, proving one's right to claim compensation can be done by all evidence methods. Court precedents have shown that the compensation for deprivation of the right of irrigation is calculated through

payment of the difference in the land's value when irrigated and the land's value when un-irrigated.

It is important to note that the landowner's right to claim compensation for deprivation of the right of irrigation shall not be affected by WAJ's use of its authorities under the Law in achieving the public interest. In other words, even if an act committed by WAJ is based on a legitimate reason, such act does not absolve it from paying the necessary compensation resulting from such act.

C.3 Authority of WAJ over Water Resources

The WAJ Law clearly stipulates the powers and authority of the MWI and WAJ over the water and water resources. The Law indicates that the functions and responsibilities of WAJ are to regulate the water uses and priorities and the water resources, to prevent its waste, to conserve its consumption¹² and to provide additional water resources¹³.

Allow us to stop for a moment to look into the term "conservation of consumption" as it holds within it the authority of WAJ in directing the use of water resources to serve the public interest and good, or at least to serve the majority's interest even if this conflicts with the public interest. For example, if the interest of providing drinking water to consumers contravenes with the interest of irrigation, then the first interest should prevail and WAJ should direct the use of water resources to satisfy the more substantive interest. This all falls within the concept of "conservation of consumption" stipulated in the WAJ Law.

The legislation in force has provided WAJ with several reallocation options. These are:

- a- Expropriation of property, lands and the water rights thereon, in accordance with the Expropriation Law in force.
- b- Buyout.
- c- Lease¹⁴.
- d- Requisition (immediate possession) in cases necessary for ensuring public safety and defense of the Kingdom and the application of martial law¹⁵.

The focus here is on options (a-c), since option (d) is an option exercised by the Government in cases of emergency and urgency and is a non-voluntary option to the owner.

The administration of options (a-c) shall always be bound by the public interest and should be conducted according to the legal procedures pertinent thereto, whereas the water resources such as wells or springs, relate to other private interests such as ownership or the citizen's entitlement rights to such water resources such as the right of irrigation. The administration of such options will result in compensating private interests for the harm and damages inflicted on them.

Expropriation of land on which a well or spring is located is an option for reallocation granted by law. However, this does not absolve WAJ from compensating the landowner, for expropriation is considered as a form of deprivation of ownership, right of disposition,

¹² Article (6) of the WAJ Law.

¹³ Articles (6), (10) and (23) of the WAJ Law.

¹⁴ Options (a-c) are in Article (23/a/3) of the WAJ Law and Article (13) of the Groundwater Control Regulation.

¹⁵ Articles (3) and (4) of the Defense Law No (13) for the Year 1992, and Article (8) of the Civil Defense Law and its amendments No (18) for the Year 1999.

usufruct or easement. Hence, the Expropriation Law has provided for procedures to be followed when conducting such. In other words, even if the act conducted by WAJ is founded on a legal basis, such act does not absolve it from paying the necessary compensation resulting there from.

The principle of compensation for expropriation was first established in the Constitution as it stipulates “No one’s property shall be expropriated unless for a just compensation”. This principle was reinforced in the Expropriation Law and procedures therein, whereby the WAJ needs to assess beforehand the compensation for the land to be expropriated, with the exclusion of compensation for harm or damages that extend beyond the expropriated land, which cannot be assessed beforehand and which is based on the interest of those requesting the compensation and the assessment of which is based on the competent court’s discretion. Moreover, the WAJ Law stipulates that if any dispute occurs between the WAJ and landlords concerning the amount of compensation to be paid against the expropriation of properties, land and related rights, or the rights of water projects and public sewerage, then either party may appeal to the Court to specify the amount in accordance with the provisions of the Expropriation Law in effect. They may also agree to refer the case to arbitration in accordance with the Arbitration Law in effect¹⁶.

WAJ is not permitted to deprive an owner of ownership or takes possession over a property without undergoing the legal procedures necessary, such as following the legal procedures for expropriation. Forceful possession would be an infringement on the owner’s rights, for which WAJ is compelled to compensate for the harm and damages caused according to the concept of “harm” in the Civil Code, which deals with the material and immaterial harm and the lost gain, in addition to returning the status of the property to its original state prior to the wrongful act.

As for options (b-c), which are buyout and lease, these are contractual relationships based on the mutual agreement of WAJ and the well owner. These options are also based on an injured party receiving just and adequate compensation for the harm and/or damages incurred as a result of such actions. The injured party may be other than the property owner, as described previously.

Meetings with WAJ officials indicate that in practice and in recent times, the WAJ has not undertaken any expropriation procedures, for most of the wells of interest to them they already owned. As to buyouts, they have performed certain buyout transactions for closed wells or weak wells. They tried to buy some working wells, but the well owners asked outrageous prices for their wells, and WAJ decided to move away from using this option. The most used option is lease, whereby WAJ has rented certain wells for a short period of time (usually 3-4 months) to meet WAJ’s immediate needs.

In addition to what is stated above and from reviewing the license granted for wells, it is interesting to note that such license contains a provision whereby the licensee shall allow WAJ to pump water from the well, wholly or partially, to be used for drinking purposes if need be. This provision gives WAJ the authority to pump unlimited amounts of water from any irrigation well to be used for drinking purposes if the need arises for such, and without needing permission from the licensee. However, under the general rules of law, this sort of act will require compensating the licensee for taking away their right to extract and use the water, which they acquired from their license.

¹⁶ Article (26) of the WAJ Law.

C.4 Summary and Conclusions

The general conclusion from the legal research and interviews is that a strong legal basis exists for WAJ to undertake the reallocation of water resources for the public good. The provisions of the law and regulations provide WAJ with all the means necessary. The pressing need is for WAJ to actually use the remedies provided under the law. From studying the legal provisions closely, and the obvious reallocation options provided therein, we have arrived at several suggestions on where WAJ might strengthen its program of activities from a legal standpoint:

- Strengthening the control over water resources in order to protect such from infringements thereon.
- Activating the provisions of the WAJ Law and the Groundwater Control Regulation with regard to groundwater abstractions and licenses.
- Clarifying the authority of WAJ as stated in Article (6/c/h) of the WAJ Law, with respect to directing the establishment of wells and the conservation of consumption, which should include WAJ's authority to close wells to reduce over-abstraction from aquifers, or to transfer irrigation wells to other uses, especially for domestic use.
- Revising the extraction fees by increasing them in order to reduce the extraction of water and safeguard from depletion and increase the availability of drinking water. The Constitution states in Article (111) thereof that no fee or tax shall be imposed except by law, whereby we find the basis of these fees in the Regulation in Article (32) of the WAJ Law. Hence, amending such fees will require amendments to the Regulation. This should not prove to be a difficult task, for the fees in the Regulation have been amended twice since passing the Regulation in the Year 2002: in the Amendment No (76) for the Year 2003, which was passed on 1/7/2003; and in Amendment No (68) for the Year 2004, which was passed on 1/6/2004.
- Requiring a bank guarantee on irrigation wells. Currently, the WAJ stipulates that the applicant for a license should provide WAJ with a monetary or bank guarantee prior to the issuance of the license; the guarantee is forfeited if the license is violated, based on conditions and bases set by the Council of Ministers. However, the decision of the Council of Ministers included wells used for industry, tourism and universities, but did not include applicants for an irrigation well. The amount of this guarantee is 50,000 dinars. We believe that WAJ should seek another decision from the Council of Ministers, whereby irrigation wells should be included therein in order to assist in limiting the number of new irrigation wells.
- Establishing a special water court. There seems to be a lack of clarity within the current court system with regard to the sensitivity of the issues related to water, and the application of the procedures concerning water crimes and the punishment thereof. It has been suggested in several meetings with water specialists that creating a court specialized in water crimes and sanctions might help solve the problem.

- Clarifying the available enforcement procedures. Based on interviews, there is confusion amongst WAJ employees on the steps or procedures that should be undertaken in accordance with the provisions of the Law and Regulation. There is limited awareness on the relevant authority to which crimes should be reported, which is the General District Attorney. Moreover, cooperation and collaboration between WAJ and other official bodies should be enhanced in order to assist WAJ and its employees in performing their duties set out under the Law.

Appendix D

Tabaqat Fahel and Wadi Al Arab Water Quality

D.1 General

The purpose of this section is to provide a response to comments from WAJ regarding the following water quality issues:

- In the workshop on the Basis of Planning, WAJ expressed concern that elevated levels of biological contamination existed in Tabaqat Fahel water in recent years, and asked the NGWTFS team to review and comment on this.
- In their comments on the Draft Feasibility report, WAJ requested the NGWTFS team to look into the issue of infection of the Wadi Al Arab wells by iron and sulfur bacteria.

D.2 Tabaqat Fahel Water Quality Data

A thorough search for water quality data on the Tabaqat Fahel springs uncovered additional data that was not available before the workshop on the Basis of Planning. The sources of the new data included: the WAJ Central Lab in Amman ,who provided data in electronic files; and the WAJ Irbid Lab, who provided new data, some in hard copies and some in Electronic format. All of the new data were reviewed, tabulated and consolidated in one electronic file, taking care to exclude data which repeated among the data sources. The data on turbidity is illustrated on **Figure D-1 and Figure D-2;** and the data on coliforms and faecal coliforms are shown on **Figure D-3 and Figure D-4.** All the data are included in **Table D-1.**

Figure D-1 Tabaqat Fahel Wells: Turbidity

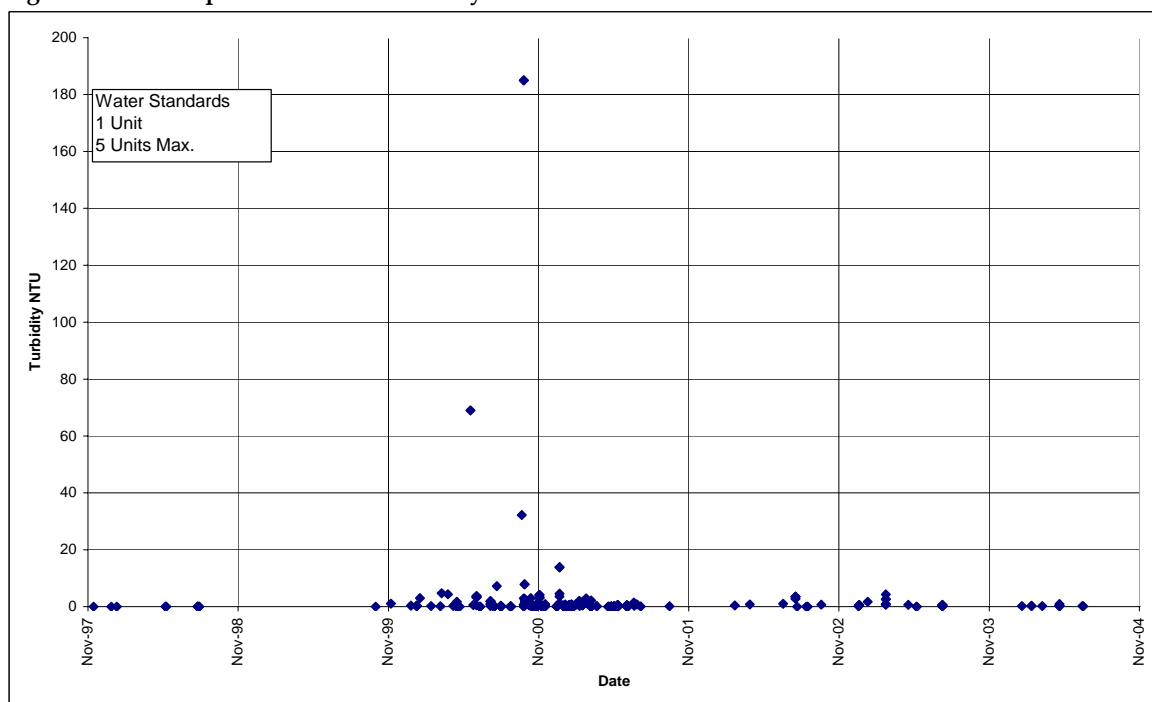


Figure D-2 Tabaqat Fahel: Turbidity

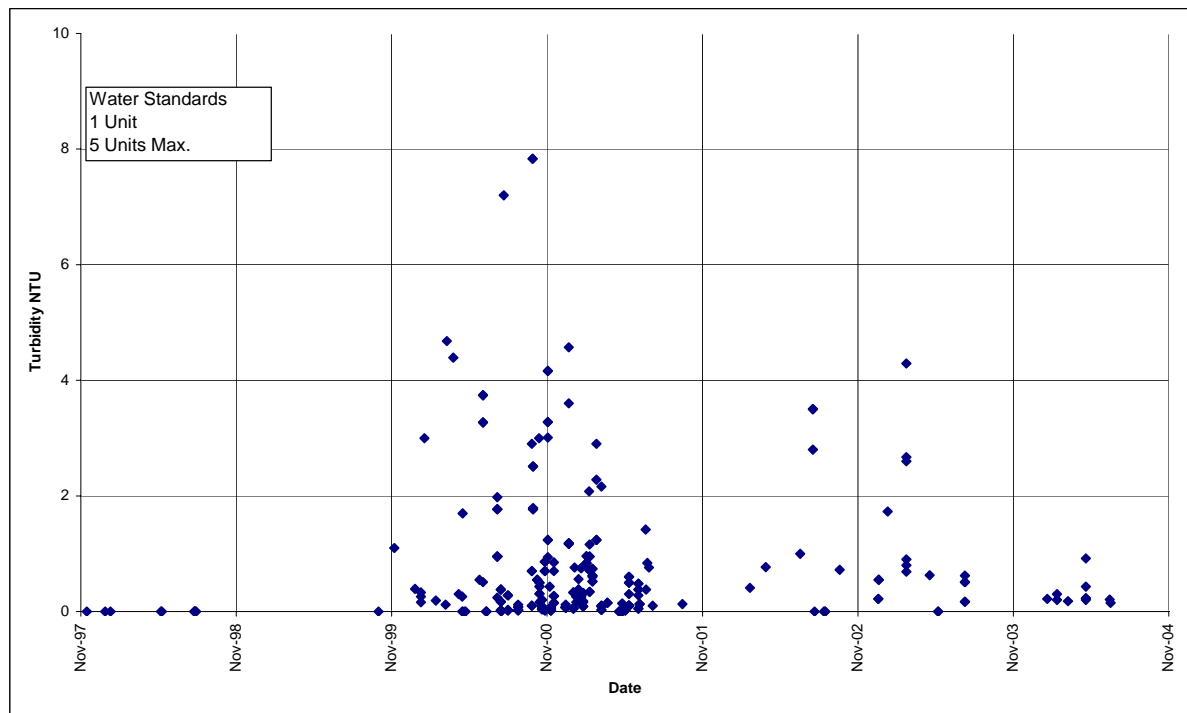


Figure D-3 Tabaqat Fahel: Faecal Coliform and E-Coli

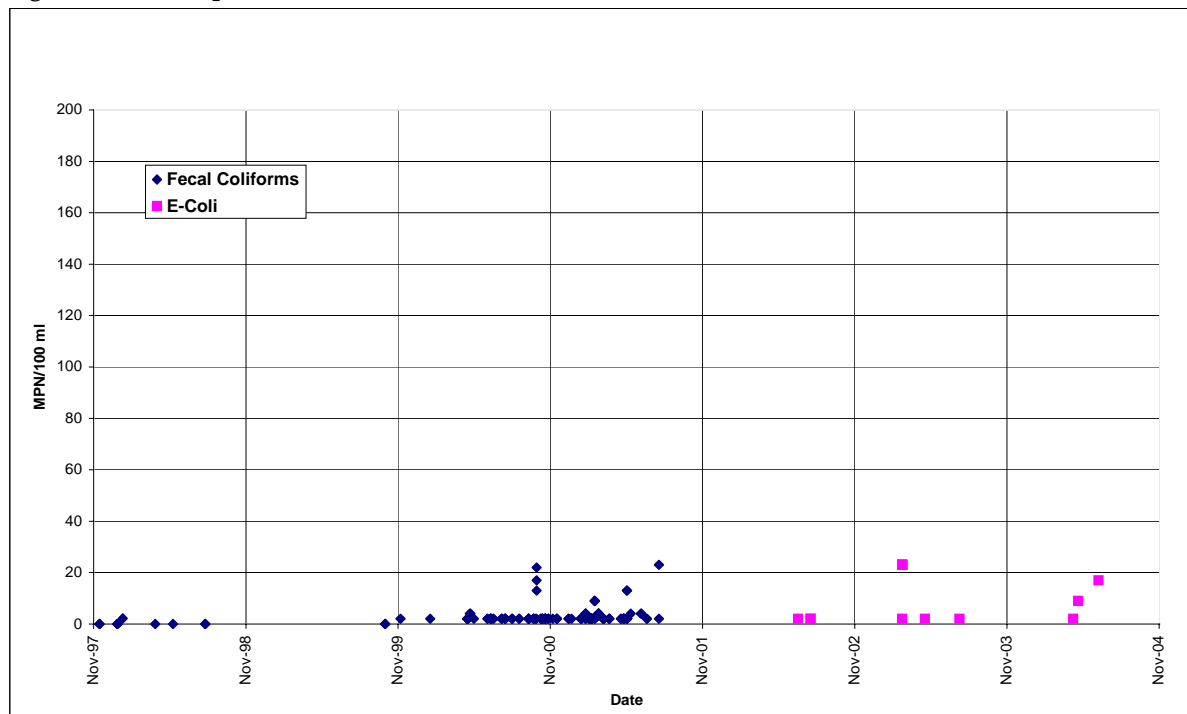
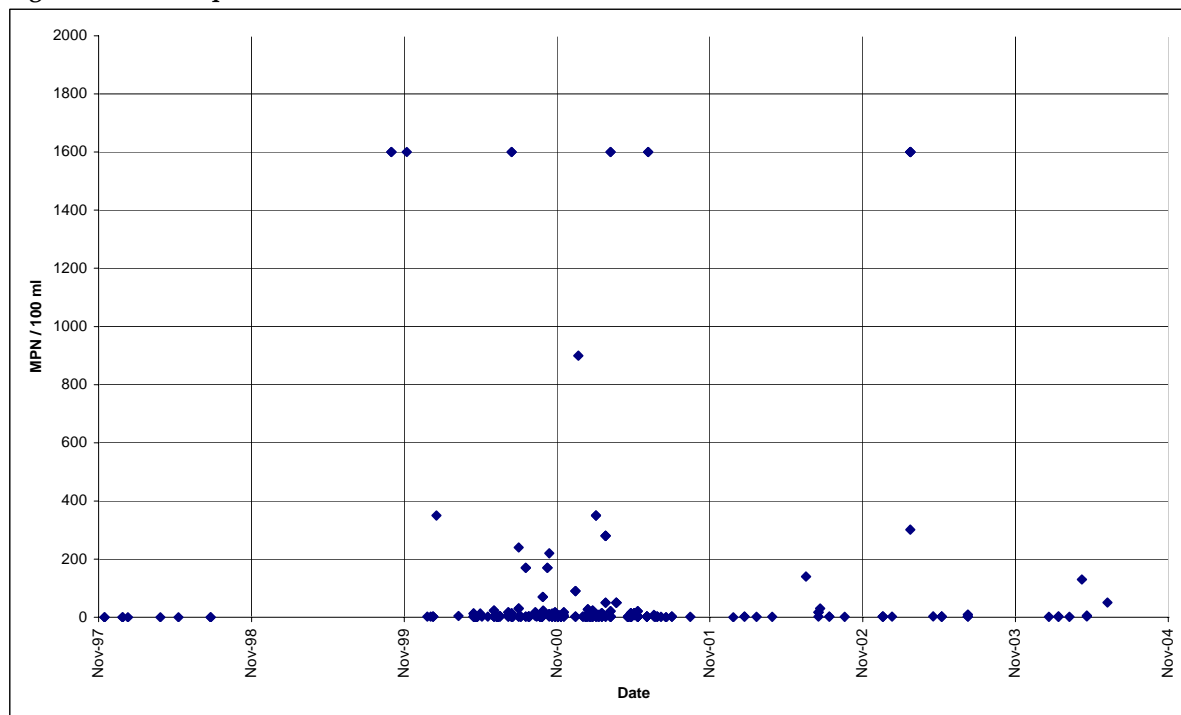


Figure D-4 Tabaqat Fahel: Total Coliforms

The turbidity data indicate a decline after year 2000; starting in 2003 the turbidity levels are in the range of 1 NTU, thus meeting the Jordanian Standards for this parameter.

The data on Total Coliform levels are less than 200 for most of the samples, especially for the data taken after mid-2001.

The data on Faecal Coliforms and *E-Coli* show levels of less than or slightly above the 20 MPN/100 ml threshold.

D.3 Iron and Sulfur Bacteria in Wadi Arab Wells

Iron and sulfur bacteria have been noticed in the Wadi Arab wells. Iron bacteria are oxidizing agents that combine iron or manganese dissolved in ground water with oxygen. A side effect of the process is a foul-smelling brown slime which coats the well screens, causing odors and clogging well screens and pipes. There are several signs that may indicate an iron bacteria problem. Water may have a yellow, red or orange color. A strange smell resembling fuel oil, cucumbers, or sewage may be noticeable. NGWA lab authorities have indicated that they noticed a distinct “petroleum-like” odor – they thought that this was perhaps due to the fact that some of the pipelines used to convey the well water were old, and had in fact at one time been used to convey petroleum products. Most probably, this is not the case, and the fuel oil smell is simply a typical indicator of the presence of iron bacteria.

Sulfur-oxidizing bacteria produce effects similar to those of iron bacteria. They convert sulfide into sulfate, producing a dark slime that can clog plumbing. Sulfur-reducing bacteria live in an oxygen-deficient environment. They break down sulfur compounds, producing

hydrogen sulfide gas in the process. Hydrogen sulfide gas is foul-smelling and highly corrosive. Of the two types, sulfur-reducing bacteria are the more common. The most obvious sign of a sulfur bacteria problem is the distinctive "rotten egg" odor of hydrogen sulfide gas.

The problem first appeared in 2002, during routine examination at Wadi Arab WTP¹. The water had an unpleasant odor, and brown slimes appeared in the settling basin. The problem was traced back initially to Himma well and Wadi Al Arab well # 7, which was found to have 2-4 mg/L of H₂S. Well #7 was removed from service, and use of the Himma well for drinking water was also stopped. At about the same time, other wells became infected: Wells # 1, 4, 5, 7, 8 and 9 (the last two of which are relatively new and have not yet been used for drinking water supply). The first sampling for Well #8 was taken in 2002, and for Well #9 in 2003, these samples were taken after completing the well construction.

Prevention is the best treatment for both iron and sulfur bacteria and it is imperative that NGWA maintain the well-drilling disinfection processes recently started in order to avoid spreading of the problem. Tools, pumps, pipe, gravel pack material, and even water used during drilling should be treated with a 200 mg/L chlorine solution. Anything that will be going into the ground during the drilling process must be disinfected.

Iron bacteria and sulfur bacteria contamination often occur at the same time and cannot be distinguished from each other; the two types of bacteria often live together in a complex symbiotic relationship. Fortunately, both types of bacteria can be treated using the same methods, as follows.

- **Shock Chlorination and Acid Treatment.** Chlorine is highly toxic to coliforms and similar types of bacteria, but less so for iron and sulfur bacteria as a result of the protective slimy substrate. A standard chlorine treatment may kill cells on the slime surface but leave the embedded bacteria unaffected. Moreover, iron dissolved in the water also exerts a chlorine demand, which has to be overcome before the chlorine is effective on the bacteria. For severe cases, treatment with a strong acid and salt solution following a thorough shock chlorination may be required. The acid solution (hydrochloric acid) may be able to penetrate thick incrustations of bacteria that the chlorine solution was unable to kill. Specifically at Wadi Arab:
- Well #9 was shock chlorinated in two stages. First stage - 19 Aug to 28 Sep 2003 - in three steps (32% HCl, 2000 mg/l KMnO₄, and then 1000 mg/l Cl₂ with air pressure). Second Stage - 22 Oct to 2 Dec - using the same three steps as in Stage 1, but with higher air pressure (over 400 psi). As a result of this, well production increased from 100 to 300 m³/h. Well #8 is slated to be chlorinated soon.
- Dosage and frequency of continuous well chlorination: This method was applied at Wells 1, 4, 5, and 7, and subsequently discontinued. Continuous chlorination is still used at Well #5. The dosage is in the range of 2-5 mg/l, sufficient to obtain 1.5 mg/l at the inlet to the water treatment plant.

Follow-up Procedures - Shock chlorination with acid will solve the immediate problems associated with iron or sulfur bacteria (odor, slime, etc.), but this is not a good long-term solution. As noticed in the Wadi Arab wells, iron and sulfur bacteria tend to build up again in a few months after treatment. To prevent bacterial regrowth, shock chlorination will have

¹ For complete details, refer to "Technical Report on Wadi Al Arab Treatment Plant" prepared by WAJ Laboratory, 2003.

to be repeated in addition to continuous chlorination into the well. As a last resort, the well may have to be abandoned (as has been done in Himma well) and a new well drilled.

Table D-1 Tabaqet Fahel Wells Water Quality Data																																				
					C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CaCO3			MPN	MPN	MPN	mg/L	mg/L	mg/L	
Data Source	CDM ID	Date	WAI ID	Well or Spring	Temp	DO	E	CO2	H2S	COLOR	TOC	R. Cl.2	EC	PH	TDS	TSS	Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	NO3	15.16	Hardness	Alkalinity	EC	FC	TC	TOC	NH4	PO4		
WAJ Central Lab		15-Nov-97		Combined									857	7.78												15.16					130	130		<0.1		
WAJ Central Lab		15-Nov-97		Combined																										14	170					
WAJ Central Lab		28-Dec-97		Combined									870	7.65			5.33	2.36	1.5	0.1	9.29	0.39	0.0	6.72	15.02					30	900		<0.1	<0.02		
WAJ Central Lab		28-Dec-97		Combined																										30						
WAJ Central Lab		28-Dec-97		Combined																										23	1600					
WAJ Central Lab		10-Jan-98		Combined									887	7.57												15.07				<2.2	500		<0.1	0.01		
WAJ Central Lab		29-Mar-98		Combined																										17	90					
WAJ Central Lab		9-May-98		Well 1									859	7.45			5.14	2.51	1.55	0.1	1.71	0.85	0.0	6.38	15.28											
WAJ Central Lab		10-May-98		Well 1									849	7.52			5.1	2.66	1.55	0.1	1.75	0.87	0.0	6.45	15.43											
WAJ Central Lab		10-May-98		Well 1																																
WAJ Central Lab		11-May-98		Well 1									859	7.53			5.21	2.49	1.56	0.1	1.83	0.89	0.0	6.35	15.13					70	140					
WAJ Central Lab		26-Jul-98		Well 4									869	7.34			4.84	2.60	1.44	0.10	1.63	0.73	0.0	6.32	15.25											
WAJ Central Lab		27-Jul-98		Combined									872	7.42			4.82	2.78	1.47	0.1	1.70	0.73	0.0	6.63	14.59					220	350		0.13	0.04		
WAJ Central Lab		27-Jul-98		Well 4																																
WAJ Central Lab		27-Jul-98		Well 4									862	7.24			4.72	2.54	1.44	0.10	1.66	0.72	0.0	6.20	15.04					130	130					
WAJ Central Lab		27-Jul-98		Well 4																																
WAJ Central Lab		30-Jul-98		Well 5									873	7.45			4.58	2.7	1.4	0.09	1.58	0.63	0.0	6.40	15.08											
WAJ Central Lab		30-Jul-98		Well 5									873	7.43			4.58	2.72	1.34	0.08	1.57	0.63	0.0	6.40	15.17											
WAJ Central Lab		30-Jul-98		Well 5																																
WAJ Central Lab		3-Oct-99		Combined																											280	≥1600		<0.1	<0.02	
WAJ Central Lab		3-Oct-99		Combined																											1600	≥1600				
WAJ Irbid Lab	54	9-Nov-99	2100 L	Combined									885	7.70	435		101.1	34.9	40.5	4.30	76.70	51.2	0.0	392.8	16.90	395.70			<2	>1600		<0.1	0.05			
WAJ Irbid Lab	68	28-Dec-99	2171L	Well 2								without	933	7.24	597		104.2	27.7	40.0	3.40	72.80		0.0	387.0	13.60	374.00					<2		<0.1	0.03		
WAJ Irbid Lab	128	5-Jan-00		Well 3																											<2					
WAJ Irbid Lab	18	11-Jan-00	42 L	Well 6								without																			<2					
WAJ Irbid Lab	85	11-Jan-00	41 L	Well 3								without																			<2					
WAJ Irbid Lab	143	11-Jan-00	40 L	Well 1								without																			<2					
WAJ Irbid Lab	55	19-Jan-00	29 L		17.8							without	917	7.66	587		59.3	33.1	42.0	4.50	76.80	38.4	0.0	389.4	19.10	384.00			<2		350		<0.1	0.16		
WAJ Irbid Lab	108	15-Feb-00	59 L	Combined	20.7								979	7.20	627		97.8	34.5		42.50	74.80	40.3	0.0	394.5	19.00	386.00							<0.1	0.05		
WAJ Irbid Lab Elec.		9-Mar-00		Well 9									899	7.07	575		101.8	31.6	44		70.9	51.8			386.9	15.50	384						<0.1	0.12		
WAJ Irbid Lab	109	12-Mar-00	82 L	Combined	22.9								916	7.27	586		102.6	34.7	46.0	3.70	74.80	44.2	0.0	384.0	15.72	386.00				4		<0.1	0.18			
WAJ Irbid Lab	152	27-Mar-00	89 L	Well 1	17.9								904	7.60	579		105.0	33.1	44.0	3.70	72.89	49.9	0.0	409.9	15.19	398.00							0.100	0.11		
WAJ Central Lab		8-Apr-00		Well 1																																
WAJ Irbid Lab	152	9-Apr-00	111 L	Well 1	23.3								778	7.17	498		101.0	34.5	42.5	2.75	74.80	51.8	0.0	386.7	15.42	394.00							<0.1	0.03		
WAJ Irbid Lab	127	17-Apr-00		Well 1																										<2	13					
WAJ Irbid Lab	152	17-Apr-00	136 L	Well 1	17.0								845	6.93	541		104.5	30.0	49.0	3.50	78.70	52.7	0.0	386.9	16.00	348.20			<2		13		<0.1	0.02		
WAJ Central Lab		17-Apr-00		Well 1									909	7.32			4.77	3.09	1.67	0.09	1.93	0.79	0.00	6.58	17.58						<2		0.13	<0.02		
WAJ Central Lab		17-Apr-00		Well 1																												<2				
WAJ Central Lab		17-Apr-00		Well 1																																
WAJ Irbid Lab	69	18-Apr-00	147 L	Well 3									953	6.97	610		109.9	22.9	59.0	3.60	78.70	56.4	0.0	386.9	15.64	368.50			<2	4		<0.1	0.09			
WAJ Irbid Lab	128	18-Apr-00		Well 3																												<2				
WAJ Irbid Lab	128	18-Apr-00		Well 3																										<2	4					
WAJ Irbid Lab	128	18-Apr-00		Well 3																										<2	4					
WAJ Irbid Lab Elec.		18-Apr-00		Well 3																										<2	4					
WAJ Irbid Lab Elec.		18-Apr-00		Well 3																										<2	4					
WAJ Central Lab		19-Apr-00		Well 3									916	7.20			4.38	2.85	1.62	0.10	1.93	0.81	0.00	6.01	16.76				<2	4			0.18	<0.02		
WAJ Central Lab		19-Apr-00		Well 3																										<2	4					
WAJ Central Lab		19-Apr-00		Well 3																																

Table D-1

Table D-1 Tabaqet Fahel Wells Water Quality Data																																			
					C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CaCO3			MPN	MPN	MPN	mg/L	mg/L	mg/L
Data Source	CDM ID	Date	WAJ ID	Well or Spring	Temp	DO	E	CO2	H2S	COLOR	TOC	R. Cl2	EC	PH	TDS	TSS	Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	NO3	Hardness	Alkalinity	EC	FC	TC	TOC	NH4	PO4		
WAJ Irbid Lab	66	5-Jun-00	221 L	Well 5									863	6.86	552		109.2	26.7	43.5	3.40	73.90	45.2	0.0	386.9	15.90	382.00							<0.1	0.03	
WAJ Irbid Lab	70	5-Jun-00	220 L	Well 3									884	6.85	556		105.3	33	46.0	3.60	77.80	50.8	0.0	397.1	15.68	398.00						<0.1	0.01		
WAJ Irbid Lab	127	5-Jun-00		Well 1																									<2	23					
WAJ Irbid Lab	129	5-Jun-00		Well 5																									<2						
WAJ Irbid Lab	152	5-Jun-00	219 L	Well 1								without	860	6.78	550		109.9	26.2	37.5	3.70	77.80	39.5	0.0	371.5	15.46	382.00		<2	23			<0.1	0.01		
WAJ Irbid Lab	158	5-Jun-00	220 L	Well 3								without	884	6.85	556		105.3	32.9	46.0	3.60	77.80	50.8	0.0	397.1	15.68	398.00				<2		<0.1	0.01		
WAJ Irbid Lab	158	5-Jun-00	221 L	Well 5								without	863	6.86	552		109.2	26.7	43.5	3.40	73.90	45.2	0.0	386.9	15.90	382.00			<2		<0.1	0.03			
WAJ Central Lab		13-Jun-00		Well 1									893	7.06			4.40	2.75	1.71	0.09	2.02	0.89	0.00	5.77	16.98			<2	2			<0.1	<0.02		
WAJ Central Lab		13-Jun-00		Well 1																										<2					
WAJ Central Lab		13-Jun-00		Well 3									900	7.02			4.61	2.92	1.76	0.10	2.06	0.91	0.00	6.09	16.44			<2	90			<0.1	<0.02		
WAJ Central Lab		13-Jun-00		Well 3																									<2	80					
WAJ Central Lab		13-Jun-00		Well 5									885	7.11			4.10	2.61	1.68	0.09	1.94	0.85	0.00	5.58	17.66			<2	13			<0.1	<0.02		
WAJ Central Lab		13-Jun-00		Well 5																									<2	4					
WAJ Central Lab		13-Jun-00		Well 1																															
WAJ Central Lab		13-Jun-00		Well 3																															
WAJ Central Lab		15-Jun-00		Well 1																															
WAJ Central Lab		15-Jun-00		Well 5																															
WAJ Irbid Lab	128	19-Jun-00		Well 3																											<2				
WAJ Irbid Lab	129	19-Jun-00		Well 5																									<2	4					
WAJ Irbid Lab Elec.		19-Jun-00		Well 3																											<2				
WAJ Irbid Lab Elec.		19-Jun-00		Well 5																											<2	4			
WAJ Irbid Lab	66	9-Jul-00	346 L	Well 5																															
WAJ Irbid Lab	67	9-Jul-00		Well 5																															
WAJ Irbid Lab	71	9-Jul-00	345 L	Well 3																															
WAJ Irbid Lab	110	9-Jul-00		Combined	22.0								1014	7.32	649		103.4	30.1	38.5	3.10	75.51	36.5	0.0	386.8	15.20	382.00						<0.1	0.00		
WAJ Irbid Lab	127	9-Jul-00		Well 1																									<2	7					
WAJ Irbid Lab	128	9-Jul-00		Well 3																									<2	17					
WAJ Irbid Lab	129	9-Jul-00		Well 5																										<2					
WAJ Irbid Lab	152	9-Jul-00	344 L	Well 1																															
WAJ Irbid Lab Elec.		9-Jul-00		Well 3																											<2	17			
WAJ Irbid Lab Elec.		9-Jul-00		Well 5																											<2				
WAJ Irbid Lab	66	17-Jul-00	373 L	Well 5																															
WAJ Irbid Lab	72	17-Jul-00	372 L	Well 3																															
WAJ Irbid Lab	127	17-Jul-00		Well 1																									<2	14					
WAJ Irbid Lab	128	17-Jul-00		Well 3																										<2					
WAJ Irbid Lab	129	17-Jul-00		Well 5																									21	≥1600					
WAJ Irbid Lab	152	17-Jul-00	371 L	Well 1																															
WAJ Irbid Lab Elec.		17-Jul-00		Well 3																											<2				
WAJ Irbid Lab Elec.		17-Jul-00		Well 5																											21	>1600			
WAJ Central Lab		18-Jul-00		Combined									890	7.13			5.00	2.84	1.58	0.09	2.02	0.76	0.0	6.46	15.46			<2	17			<0.1	<0.02		
WAJ Central Lab		18-Jul-00		Combined																									<2	4					
WAJ Irbid Lab	111	24-Jul-00	411 L	Combined																															
WAJ Irbid Lab	66	3-Aug-00	460 L	Well 5																															
WAJ Irbid Lab	73	3-Aug-00	459 L	Well 3																															
WAJ Irbid Lab	127	3-Aug-00		Well 1																									<2	240					
WAJ Irbid Lab	128	3-Aug-00		Well 3																										<2					
WAJ Irbid Lab	129	3-Aug-00		Well 5																									<2	30					
WAJ Irbid Lab	151	3-Aug-00	458 L	Well 1																															
WAJ Irbid Lab Elec.		3-Aug-00		Well 3																											<2				
WAJ Irbid Lab Elec.		3-Aug-00		Well 5																											<2	30			
WAJ Irbid Lab	127	8-Aug-00		Well 1																										<2					
WAJ Irbid Lab	129	8-Aug-00		Well 5																										<2					
WAJ Irbid Lab Elec.		8-Aug-00		Well 5																										<2					
WAJ Irbid Lab	127	20-Aug-00		Well 1																											<2				
WAJ Irbid Lab	128	20-Aug-00		Well 3																										<2					
WAJ Irbid Lab	129	20-Aug-00		Well 5																									<2	170					
WAJ Irbid Lab Elec.		20-Aug-00		Well 5																									<2	170					
WAJ Irbid Lab	65	27-Aug-00	572 L	Well 5																															
WAJ Irbid Lab	74	27-Aug-00	571 L	Well 3																															

Table D-1

Table D-1 Tabaqet Fahel Wells Water Quality Data																																							
Data Source	CDM ID	Date	WAJ ID	Well or Spring	Temp	C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CaCO3			MPN	MPN	MPN	mg/L	mg/L	mg/L		
						DO		E	CO2	H2S	COLOR	TOC	R. Cl2	EC	PH	TDS	TSS	Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	NO3	Hardness	Alkalinity	EC	FC	TC	TOC	NH4	PO4					
WAJ Irbid Lab	127	27-Aug-00		Well 1																																			
WAJ Irbid Lab	128	27-Aug-00		Well 3																																			
WAJ Irbid Lab	129	27-Aug-00		Well 5																																			
WAJ Irbid Lab	151	27-Aug-00	570 L	Well 1																																			
WAJ Irbid Lab	155	27-Aug-00	570 L	Well 1																																			
WAJ Irbid Lab Elec.		27-Aug-00		Well 3																																			
WAJ Irbid Lab Elec.		27-Aug-00		Well 5																																			
WAJ Irbid Lab Elec.		29-Aug-00		Well 3																																			
WAJ Irbid Lab	127	12-Sep-00		Well 1																																			
WAJ Irbid Lab	128	12-Sep-00		Well 3																																			
WAJ Irbid Lab	129	12-Sep-00		Well 5																																			
WAJ Irbid Lab Elec.		12-Sep-00		Well 3																																			
WAJ Irbid Lab Elec.		12-Sep-00		Well 5																																			
WAJ Irbid Lab	130	15-Sep-00		Well 6																																			
WAJ Irbid Lab	20	23-Sep-00	636 L	Well 6										756	7.20	484		99.4	28.7	35.0	3.00	45.30	57.6	0.0	374.8	16.30	366.00												
WAJ Irbid Lab	130	23-Sep-00		Well 6																																			
WAJ Irbid Lab	130	23-Sep-00		Well 6																																			
WAJ Irbid Lab Elec.		23-Sep-00		Well 6																																			
WAJ Irbid Lab	128	24-Sep-00		Well 3																																			
WAJ Irbid Lab	129	24-Sep-00		Well 5																																			
WAJ Irbid Lab Elec.		24-Sep-00		Well 3																																			
WAJ Irbid Lab Elec.		24-Sep-00		Well 5																																			
WAJ Irbid Lab	21	28-Sep-00	650 L											without	866	7.32	554		88.0	39.0	40.0	3.20	64.90	48.0	0.0	398.3	19.80	380.00											
WAJ Irbid Lab	65	28-Sep-00	649 L	Well 5										without	889	7.16																							
WAJ Irbid Lab	75	28-Sep-00	647 L	Well 3										without	880	7.20																							
WAJ Irbid Lab	127	28-Sep-00		Well 1																																			
WAJ Irbid Lab	128	28-Sep-00		Well 3																																			
WAJ Irbid Lab	129	28-Sep-00		Well 5																																			
WAJ Irbid Lab	130	28-Sep-00		Well 6																																			
WAJ Irbid Lab	151	28-Sep-00	648 L	Well 1										without	906	7.15																							
WAJ Irbid Lab Elec.		28-Sep-00		Well 3											808	7.2	563																						
WAJ Irbid Lab Elec.		28-Sep-00		Well 5											889	7.16	589.9																						
WAJ Irbid Lab Elec.		28-Sep-00		Well 6											866	7.32	554.2		88	39	40	3.2	64.9	48	0	398.3	19.80	380											
WAJ Irbid Lab	22	30-Sep-00	653 L	Well 6										1031	6.90																								
WAJ Irbid Lab	130	30-Sep-00		Well 6																																			
WAJ Irbid Lab Elec.		30-Sep-00		Well 6										1013	6.9	648.3																							
WAJ Irbid Lab	65	1-Oct-00	656 L	Well 5										896	7.38																								
WAJ Irbid Lab	76	1-Oct-00	655 L	Well 3										900	7.29																								
WAJ Irbid Lab	127	1-Oct-00		Well 1																																			
WAJ Irbid Lab	128	1-Oct-00		Well 3																																			
WAJ Irbid Lab	129	1-Oct-00		Well 5																																			
WAJ Irbid Lab	153	1-Oct-00	654 L	Well 1										903	7.37																								
WAJ Irbid Lab Elec.		1-Oct-00		Well 3										900	7.29	576																							
WAJ Irbid Lab Elec.		1-Oct-00		Well 5										896	7.38	573.4																							
WAJ Irbid Lab	64	11-Oct-00	700 L	Well 5										897	7.25																								
WAJ Irbid Lab	129	11-Oct-00		Well 5																																			
WAJ Irbid Lab Elec.		11-Oct-00		Well 5										897	7.25	574																							
WAJ Irbid Lab	112	15-Oct-00	701 L	Combined										885	7.30																								
WAJ Irbid Lab	127	15-Oct-00		Well 1																																			
WAJ Irbid Lab	128	15-Oct-00		Well 3																																			
WAJ Irbid Lab	129	15-Oct-00		Well 5																																			
WAJ Irbid Lab Elec.		15-Oct-00		Well 3																																			
WAJ Irbid Lab Elec.		15-Oct-00		Well 6																																			
WAJ Irbid Lab	23	16-Oct-00	715 L	Well 6										858	6.83																								
WAJ Irbid Lab	63	16-Oct-00	714 L	Well 5										895	6.77																								
WAJ Irbid Lab	77	16-Oct-00	713 L	Well 3										901	6.70																								
WAJ Irbid Lab	150	16-Oct-00-Oct																																					

Table D-1

Table D-1 Tabaqet Fahel Wells Water Quality Data																																		
					C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CaCO3		MPN	MPN	MPN	mg/L	mg/L	mg/L
Data Source	CDM ID	Date	WAI ID	Well or Spring	Temp	DO	E	CO2	H2S	COLOR	TOC	R. CL2	EC	PH	TDS	TSS	Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	NO3	Hardness	Alkalinity	EC	FC	TC	TOC	NH4	PO4	
WAJ Irbid Lab Elec.		16-Oct-00		Well 6									858	6.83	549										16.50								<0.1	0.06
WAJ Irbid Lab	24	22-Oct-00	730 L	Well 6									868	7.20	556		99.8	32.7	38.0	3.00	63.80	48.0	0.0	385.0	14.88	384.00						<0.1	0.02	
WAJ Irbid Lab	62	22-Oct-00	729 L	Well 5									900	7.30	576		102.2	32.2	41.5	3.50	70.50	58.7	0.0	382.6	14.97	388.00						<0.1	0.04	
WAJ Irbid Lab	78	22-Oct-00	728 L	Well 3									906	7.20	580		99.8	35.5	41.0	3.30	70.50	51.4	0.0	397.0	14.35	396.00						<0.1	0.02	
WAJ Irbid Lab	127	22-Oct-00		Well 1																									<2	13				
WAJ Irbid Lab	128	22-Oct-00		Well 3																									<2	2.0				
WAJ Irbid Lab	129	22-Oct-00		Well 5																									<2	2				
WAJ Irbid Lab	130	22-Oct-00		Well 6																									<2	4				
WAJ Irbid Lab	149	22-Oct-00	727 L	Well 1									903	7.30	578		103.0	31.6	43.5	3.50	75.20	52.8	0.0	382.6	14.70	388.00						<0.1	0.03	
WAJ Irbid Lab Elec.		22-Oct-00		Well 3									906	7.2	580		99.8	35.5	41	3.3	70.5	51.36	0	397	14.35	396			<2	2			<0.1	0.023
WAJ Irbid Lab Elec.		22-Oct-00		Well 5									900	7.3	576		102.2	32.2	41.5	3.5	70.5	58.7	0	382.6	14.97	388			<2	2			<0.1	0.043
WAJ Irbid Lab Elec.		22-Oct-00		Well 6									868	7.2	556		99.8	32.7	38	3	63.8	48	0	385	14.88	384			<2	4			<0.1	0.021
WAJ Irbid Lab	25	29-Oct-00	754 L	Well 6									842	7.17																				
WAJ Irbid Lab	61	29-Oct-00	753 L	Well 5									888	7.36																				
WAJ Irbid Lab	79	29-Oct-00	752 L	Well 3									873	7.16																				
WAJ Irbid Lab	127	29-Oct-00		Well 1																									<2	14				
WAJ Irbid Lab	128	29-Oct-00		Well 3																										<2				
WAJ Irbid Lab	129	29-Oct-00		Well 5																									<2	17				
WAJ Irbid Lab	130	29-Oct-00		Well 6																										<2				
WAJ Irbid Lab	148	29-Oct-00	751 L	Well 1									857	7.20																				
WAJ Irbid Lab Elec.		29-Oct-00		Well 3									873	7.16	559																<2			
WAJ Irbid Lab Elec.		29-Oct-00		Well 5									888	7.36	568														<2	17				
WAJ Irbid Lab Elec.		29-Oct-00		Well 6									842	7.17	538.9															<2				
WAJ Irbid Lab	26	5-Nov-00	800 L	Well 6									885	7.23																			<0.1	0.28
WAJ Irbid Lab	60	5-Nov-00	799 L	Well 5									920	7.13																			<0.1	0.08
WAJ Irbid Lab	80	5-Nov-00	798 L	Well 3									903	7.25																				
WAJ Irbid Lab	113	5-Nov-00	793 L	Combined									925	7.27											16.39							<0.1	0.09	
WAJ Irbid Lab	127	5-Nov-00		Well 1																										<2				
WAJ Irbid Lab	128	5-Nov-00		Well 3																										<2				
WAJ Irbid Lab	129	5-Nov-00		Well 5																										<2				
WAJ Irbid Lab	130	5-Nov-00		Well 6																										<2				
WAJ Irbid Lab	147	5-Nov-00	797 L	Well 1									950	7.05																				
WAJ Irbid Lab Elec.		5-Nov-00		Well 3									903	7.25	578																<2			
WAJ Irbid Lab Elec.		5-Nov-00		Well 5									920	7.13	588.8															<2			<0.1	0.08
WAJ Irbid Lab Elec.		5-Nov-00		Well 6									885	7.23	566.4															<2			<0.1	0.28
WAJ Irbid Lab Elec.		9-Nov-00		Well 5									884	7.26	434		102.7	34.9	36	4	75.3	49.2	0	390.4	16.00	399.8			<2	7			<0.1	0.08
WAJ Irbid Lab	27	12-Nov-00	824 L	Well 6									859	7.21																				0.04
WAJ Irbid Lab	81	12-Nov-00	823 L	Well 3									895	7.17																				
WAJ Irbid Lab	114	12-Nov-00	821 L	Combined									822	7.28											6.27							<0.1	0.02	
WAJ Irbid Lab	127	12-Nov-00		Well 1																										<2				
WAJ Irbid Lab	128	12-Nov-00		Well 3																										<2				
WAJ Irbid Lab	129	12-Nov-00		Well 5																										<2				
WAJ Irbid Lab	130	12-Nov-00		Well 6																										<2				
WAJ Irbid Lab	146	12-Nov-00	822 L	Well 1									909	7.13																				
WAJ Irbid Lab Elec.		12-Nov-00		Well 3									895	7.17	573																<2			
WAJ Irbid Lab Elec.		12-Nov-00		Well 5									792	7.79	506.9																<2			
WAJ Irbid Lab Elec.		12-Nov-00		Well 6									859	7.21	549.8																<2			
WAJ Irbid Lab	28	19-Nov-00	854 L	Well 6									854	7.43												15.80							0.100	0.02
WAJ Irbid Lab	82	19-Nov-00	853 L	Well 3									883	7.46																				
WAJ Irbid Lab	115	19-Nov-00	851 L	Combined									888	7.27																				
WAJ Irbid Lab	127	19-Nov-00		Well 1																									<2	7				
WAJ Irbid Lab	128	19-Nov-00		Well 3																									<2	17				
WAJ Irbid Lab	130	19-Nov-00		Well 6																										<2				
WAJ Irbid Lab	145	19-Nov-00	852 L	Well 1									908	7.28																				

Table D-1

Table D-1 Tabaqet Fahel Wells Water Quality Data																										
Data Source	CDM ID	Date	WAI ID	Well or Spring	Temp	C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
						DO	E	CO2	H2S	COLOR	TOC	R. CL2	EC	PH	TDS	TSS	Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	NO3	Hardness
WAJ Irbid Lab	127	17-Dec-00		Well 1																						
WAJ Irbid Lab	128	17-Dec-00		Well 3																						
WAJ Irbid Lab	129	17-Dec-00		Well 5																						
WAJ Irbid Lab	144	17-Dec-00	905 L	Well 1									902	7.07												
WAJ Irbid Lab Elec.		17-Dec-00		Well 3									892	7.05	571											
WAJ Irbid Lab Elec.		17-Dec-00		Well 5									883	7.23	565											
WAJ Irbid Lab Elec.		17-Dec-00		Well 6									846	7.24	541.4											
WAJ Irbid Lab	30	24-Dec-00	923 L	Well 1																						
WAJ Irbid Lab	30	24-Dec-00	924 L	Well 3																						
WAJ Irbid Lab	30	24-Dec-00	925 L	Well 5																						
WAJ Irbid Lab	30	24-Dec-00	926 L	Well 6																						
WAJ Irbid Lab	30	24-Dec-00	927 L	Combined																						
WAJ Irbid Lab Elec.		24-Dec-00		Well 3																						
WAJ Irbid Lab Elec.		24-Dec-00		Well 5																						
WAJ Irbid Lab Elec.		24-Dec-00		Well 6																						
WAJ Irbid Lab	19	4-Jan-01	14 L	Combined																						
WAJ Irbid Lab	37	4-Jan-01	13 L	Well 5																						
WAJ Irbid Lab	84	4-Jan-01	12 L	Well 3																						
WAJ Irbid Lab	127	4-Jan-01		Well 1																						
WAJ Irbid Lab Elec.		4-Jan-01		Well 3																						
WAJ Irbid Lab Elec.		4-Jan-01		Well 5																						
WAJ Irbid Lab Elec.		4-Jan-01		Well 6																						
WAJ Irbid Lab Elec.		7-Jan-01		Well 9									916	7.04												
WAJ Irbid Lab	127	11-Jan-01		Well 1																						
WAJ Irbid Lab	128	11-Jan-01		Well 3																						
WAJ Irbid Lab	130	11-Jan-01		Well 6																						
WAJ Irbid Lab Elec.		11-Jan-01		Well 3																						
WAJ Irbid Lab Elec.		11-Jan-01		Well 6																						
WAJ Irbid Lab	129	14-Jan-01		Well 5																						
WAJ Irbid Lab	17	16-Jan-01	65 L	Well 6								without														
WAJ Irbid Lab	38	16-Jan-01	64 L	Well 5								without														
WAJ Irbid Lab	86	16-Jan-01	63 L	Well 3								without														
WAJ Irbid Lab	127	16-Jan-01		Well 1																						
WAJ Irbid Lab	129	16-Jan-01		Well 5																						
WAJ Irbid Lab	130	16-Jan-01		Well 6																						
WAJ Irbid Lab	142	16-Jan-01	62 L	Well 1								without														
WAJ Irbid Lab Elec.		16-Jan-01		Well 3																						
WAJ Irbid Lab Elec.		16-Jan-01		Well 5																						
WAJ Irbid Lab Elec.		16-Jan-01		Well 6																						
WAJ Irbid Lab	16	22-Jan-01	80 L	Well 6								without														
WAJ Irbid Lab	39	22-Jan-01	79 L	Well 5								without														
WAJ Irbid Lab	87	22-Jan-01	78 L	Well 3								without														
WAJ Irbid Lab	127	22-Jan-01		Well 1																						
WAJ Irbid Lab	128	22-Jan-01		Well 3																						
WAJ Irbid Lab	129	22-Jan-01		Well 5																						
WAJ Irbid Lab	130	22-Jan-01		Well 6																						
WAJ Irbid Lab	141	22-Jan-01	77 L	Well 1								without														
WAJ Irbid Lab Elec.		22-Jan-01		Well 5																						
WAJ Irbid Lab Elec.		22-Jan-01		Well 6																						
WAJ Irbid Lab	15	27-Jan-01	106 L	Well 6								without														
WAJ Irbid Lab	88	27-Jan-01	105 L	Well 3								without														
WAJ Irbid Lab	127	27-Jan-01		Well 1																						
WAJ Irbid Lab	128	27-Jan-01		Well 3																						
WAJ Irbid Lab	130	27-Jan-01		Well 6																						
WAJ Irbid Lab	140	27-Jan-01	104 L	Well 1								without														
WAJ Irbid Lab Elec.		27-Jan-01		Well 3																						
WAJ Irbid Lab Elec.		27-Jan-01		Well 3																						
WAJ Irbid Lab Elec.		27-Jan-01		Well 6																						
WAJ Irbid Lab	14	4-Feb-01	121 L	Well 6								without														
WAJ Irbid Lab	127	4-Feb-01		Well 1																						
WAJ Irbid Lab	130	4-Feb-01		Well 6																						

Table D-1

Table D-1 Tabaqet Fahel Wells Water Quality Data																																					
Data Source	CDM ID	Date	WAJ ID	Well or Spring	Temp	C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CaCO3		Alkalinity	MPN	MPN	MPN	mg/L	mg/L	mg/L	
WAJ Irbid Lab	139	4-Feb-01	122 L	Well 1																																	
WAJ Irbid Lab Elec.		4-Feb-01		Well 6																																	
WAJ Irbid Lab	130	8-Feb-01		Well 6																																	
WAJ Irbid Lab	31	10-Feb-01	131 L	Well 8										without	908	7.46	581		95.0	38.5	43.0	3.70	75.70	66.5	0.0	371.0	16.70	396.00									
WAJ Irbid Lab	130	10-Feb-01		Well 8																																	
WAJ Irbid Lab	130	10-Feb-01		Well 8																																	
WAJ Irbid Lab	130	10-Feb-01		Well 8																																	
WAJ Irbid Lab Elec.		10-Feb-01		Well 8																																	
WAJ Irbid Lab Elec.		10-Feb-01		Well 8																																	
WAJ Irbid Lab	13	11-Feb-01	138 L	Well 6										without																							
WAJ Irbid Lab	40	11-Feb-01	137 L	Well 5										without																							
WAJ Irbid Lab	89	11-Feb-01	136 L	Well 3										without																							
WAJ Irbid Lab	128	11-Feb-01		Well 3																																	
WAJ Irbid Lab	129	11-Feb-01		Well 5																																	
WAJ Irbid Lab	130	11-Feb-01		Well 6																																	
WAJ Irbid Lab	138	11-Feb-01	135 L	Well 1																																	
WAJ Irbid Lab Elec.		11-Feb-01		Well 3																																	
WAJ Irbid Lab Elec.		11-Feb-01		Well 5																																	
WAJ Irbid Lab Elec.		11-Feb-01		Well 6																																	
WAJ Irbid Lab	12	18-Feb-01	155 L	Well 6										without																							
WAJ Irbid Lab	41	18-Feb-01	154 L	Well 5										without																							
WAJ Irbid Lab	90	18-Feb-01	153 L	Well 3										without																							
WAJ Irbid Lab	127	18-Feb-01		Well 1																																	
WAJ Irbid Lab	128	18-Feb-01		Well 3																																	
WAJ Irbid Lab	129	18-Feb-01		Well 5																																	
WAJ Irbid Lab	137	18-Feb-01	152 L	Well 1										without																							
WAJ Irbid Lab Elec.		18-Feb-01		Well 3																																	
WAJ Irbid Lab Elec.		18-Feb-01		Well 5																																	
WAJ Irbid Lab Elec.		18-Feb-01		Well 6																																	
WAJ Irbid Lab	11	27-Feb-01	159 L	Well 6										without	862	7.20																					
WAJ Irbid Lab	107	27-Feb-01	157 L	Combined										1.200	898	7.20																					
WAJ Irbid Lab	127	27-Feb-01		Well 1																																	
WAJ Irbid Lab	130	27-Feb-01		Well 6																																	
WAJ Irbid Lab	136	27-Feb-01	158 L	Well 1										without	898	7.40																					
WAJ Irbid Lab Elec.		27-Feb-01		Well 6											862	7.2	551.7																				
WAJ Irbid Lab	10	11-Mar-01	182 L	Well 6											862	7.20																					
WAJ Irbid Lab	42	11-Mar-01	181 L	Well 5										without	890	7.31																					
WAJ Irbid Lab	91	11-Mar-01	180 L	Well 3										without	890	7.14																					
WAJ Irbid Lab	127	11-Mar-01		Well 1																																	
WAJ Irbid Lab	128	11-Mar-01		Well 3																																	
WAJ Irbid Lab	129	11-Mar-01		Well 5																																	
WAJ Irbid Lab	130	11-Mar-01		Well 6																																	
WAJ Irbid Lab	135	11-Mar-01	179 L	Well 1										without	901	7.30																					
WAJ Irbid Lab Elec.		11-Mar-01		Well 3											890	7.14	569.6																				
WAJ Irbid Lab Elec.		11-Mar-01		Well 5																																	
WAJ Irbid Lab Elec.		11-Mar-01		Well 6											862	7.2	551.7																				
WAJ Irbid Lab	9	25-Mar-01	239 L	Well 6											858	7.41																					
WAJ Irbid Lab	130	25-Mar-01		Well 6																																	
WAJ Irbid Lab Elec.		25-Mar-01		Well 6											858	7.41	549.1																				
WAJ Central Lab		22-Apr-01		Well 5											924	7.44		5.02	2.98	1.65	0.10	1.99	0.77	0.0	6.70	14.29											
WAJ Central Lab		22-Apr-01		Well 5																																	
WAJ Central Lab		22-Apr-01		Well 6											888	7.23		4.98	2.76	1.48	0.08	1.89	0.74	0.0	6.40	16.26											
WAJ Central Lab		22-Apr-01		Well 6																																	
WAJ Central Lab		22-Apr-01		Combined											888	7.38		4.96	3.00	1.49	0.08	1.79	0.69	0.0	6.70	14.40											
WAJ Central Lab		22-Apr-01		Combined																																	
WAJ Irbid Lab	8	29-Apr-01	339 L	Well 6											857	7.12																					
WAJ Irbid Lab	43	29-Apr-01	338 L	Well 5						</																											

Table D-1

Table D-1 Tabaqet Fahel Wells Water Quality Data																																				
					C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CaCO3			MPN	MPN	MPN	mg/L	mg/L	mg/L		
Data Source	CDM ID	Date	WAI ID	Well or Spring	Temp	DO	E	CO2	H2S	COLOR	TOC	R. CL2	EC	PH	TDS	TSS	Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	NO3	Hardness	Alkalinity	EC	FC	TC	TOC	NH4	PO4			
WAJ Central Lab		29-Apr-01		Well 5																																
WAJ Central Lab		29-Apr-01		Well 6																																
WAJ Central Lab		29-Apr-01		Well 6																																
WAJ Central Lab		29-Apr-01		Combined									870	7.17			4.71	2.86	1.48	0.08	1.71	0.69	0.0	6.3	16.89				2	2						
WAJ Central Lab		29-Apr-01		Combined																																
WAJ Central Lab		29-Apr-01		Well 1																																
WAJ Central Lab		29-Apr-01		Combined																																
WAJ Irbid Lab Elec.		29-Apr-01		Well 5																																
WAJ Irbid Lab Elec.		29-Apr-01		Well 6									857	7.12	548.5																					
WAJ Irbid Lab	7	6-May-01	352 L	Well 1								without	930	7.29																						
WAJ Irbid Lab	7	6-May-01	353 L	Well 5									892	7.30																						
WAJ Irbid Lab	7	6-May-01	354 L	Well 8									892	7.26																						
WAJ Irbid Lab	7	6-May-01	355 L	Well 6									855	7.29																						
WAJ Irbid Lab	32	6-May-01	352 L	Well 1								without	930	7.29																						
WAJ Irbid Lab	32	6-May-01	353 L	Well 5									892	7.30																						
WAJ Irbid Lab	32	6-May-01	354 L	Well 8									892	7.26																						
WAJ Irbid Lab	32	6-May-01	355 L	Well 6									855	7.29																						
WAJ Irbid Lab Elec.		6-May-01		Well 8									892	7.26																						
WAJ Irbid Lab Elec.		6-May-01		Well 5									892	7.3																						
WAJ Irbid Lab Elec.		6-May-01		Well 6									855	7.29																						
WAJ Irbid Lab	6	15-May-01	378 L	Well 6									854	7.22	547		94.9	33.3	44.0	2.80	67.50	48.0	0.0	395.8	16.66	374.40										
WAJ Irbid Lab	33	15-May-01	379 L	Well 8								without	893	7.14	572		98.0	31.9	48.0	3.20	73.30	38.4	0.0	412.2	16.26	376.30										
WAJ Irbid Lab	44	15-May-01	377 L	Well 5								without	892	7.26	571		997.2	33.8	48.5	3.20		46.1	0.0	402.9	17.63	382.20										
WAJ Irbid Lab	92	15-May-01	376 L	Well 3								without	879	7.15	563		94.9	34.3	47.0	3.10	69.40	52.8	0.0	386.5	15.46	378.30										
WAJ Irbid Lab	106	15-May-01	380 L	Combined									1.500	893	7.13																					
WAJ Irbid Lab	133	15-May-01	375 L	Well 1								without	918	6.98	588		98.0	33.4	50.0	3.30	72.30	45.1	0.0	400.5	15.90											
WAJ Irbid Lab Elec.		15-May-01		Well 3									879	7.15	563		94.9	34.3	47	3.1	69.4	52.8	0	386.5	15.46	378.3										
WAJ Irbid Lab Elec.		15-May-01		Well 8									893	7.14	572		98	31.9	48	3.2	73.3	38.4	0	412.2	16.26	376.3										
WAJ Irbid Lab Elec.		15-May-01		Well 8																																
WAJ Irbid Lab Elec.		15-May-01		Well 5									892	7.26	571		97.2	33.8	48.5	3.2	73.3	46.1	0	402.9	17.63	382.2										
WAJ Irbid Lab Elec.		15-May-01		Well 6									854	7.22	547		94.9	33.3	44	2.8	67.5	48	0	395.8	16.66	374.4										
WAJ Irbid Lab	5	6-Jun-01	436 L	Well 6								without	867	7.17																						
WAJ Irbid Lab	34	6-Jun-01	437 L	Well 8								without	905	7.25																						
WAJ Irbid Lab	45	6-Jun-01	435 L	Well 5								without	915	7.13																						
WAJ Irbid Lab	132	6-Jun-01	434 L	Well 1								without	920	7.24																						
WAJ Irbid Lab Elec.		6-Jun-01		Well 8									905	7.25																						
WAJ Irbid Lab Elec.		6-Jun-01		Well 5									915	7.13																						
WAJ Irbid Lab Elec.		6-Jun-01		Well 6									867	7.17																						
WAJ Irbid Lab	93	9-Jun-01	453 L	Well 3								without	892	7.21																						
WAJ Irbid Lab Elec.		9-Jun-01		Well 3									892	7.21																						
WAJ Irbid Lab Elec.		23-Jun-01		Well 9									916	7.2	586		101.1	33.4	48		76	52.7		397.1	15.50	390										
WAJ Irbid Lab Elec.		23-Jun-01		Well 9																																
WAJ Irbid Lab	118	24-Jun-01	488 L	Well 9									908	7.48	581		100.4	33.8	46.5	3.70	76.90	48.9	0.0	397.1	16.40	390.00										
WAJ Irbid Lab Elec.		24-Jun-01		Well 9																																
WAJ Irbid Lab	119	27-Jun-01	493 L	Well 9								without	914	7.16	585		101.2	32.4	47.5	3.60	76.00	48.0	0.0	397.1	15.30	388.00										
WAJ Irbid Lab Elec.		27-Jun-01		Well 9																																
WAJ Irbid Lab	120	1-Jul-01	506 L	Well 9								without	916	7.04																						
WAJ Irbid Lab Elec.		1-Jul-01		Well 3																																
WAJ Irbid Lab Elec.		1-Jul-01		Well 8																																
WAJ Irbid Lab	105	10-Jul-01	534 L	Combined									1.200	919	6.95																					
WAJ Central Lab		22-Jul-01		Well 1																																
WAJ Central Lab		22-Jul-01		Well 1																																
WAJ Irbid Lab Elec.		5-Aug-01		Well 3																																
WAJ Irbid Lab Elec.		5-Aug-01		Well 8																																
WAJ Irbid Lab Elec.		5-Aug-01		Well 6																																
WAJ Irbid Lab	104	18-Sep-01	727 L	Combined									1.000	926	7.05																					
WAJ Central Lab		30-Dec-01		Well 1																																
WAJ Central Lab		26-Jan-02		Combined																																
WAJ Central Lab		26-Jan-02		Combined																																
WAJ Irbid Lab	102	24-Feb-02	80 L	Combined									900	7.27																						
WAJ Irbid Lab	103	2-Apr-02	68 L	Combined									2.000	888	7.45																					

Table D-1

Table D-1 Tabaqet Fahel Wells Water Quality Data																																		
					C	mg/L	Mv	mg/L	mg/L	PCU	mg/L	mg/L	Us/cm	units																				
Data Source	CDM ID	Date	WAI ID	Well or Spring	Temp	DO	E	CO2	H2S	COLOR	TOC	R. Cl2	EC	PH	TDS	TSS	Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	NO3	Hardness	Alkalinity	EC	FC	TC	TOC	NH4	PO4	
WAJ Irbid Lab Elec.		22-Jun-02		Well 6									895	7.5	573		92	43	38	3.6	72	29	0	418	19.80	406		<2		140		<0.1	0.03	
WAJ Irbid Lab	35	22-Jul-02	236 L	Well 8								without	846	7.65	541		96.0	34.0		3.30	66.00	26.0	0.0	410.0	19.40	381.00				<2		<0.1	0.04	
WAJ Irbid Lab	94	22-Jul-02	237 L	Well 3								without	882	7.41			97.0	37.0	37.0	3.60	70.00	31.0	0.0	412.0	18.00	396.00		<2		17		<0.1	0.06	
WAJ Irbid Lab Elec.		22-Jul-02		Well 3									882	7.41	564		97	37	37	3.6	70	31	0	412	18.00	396		<2		17		<0.1	0.06	
WAJ Central Lab		26-Jul-02		Well 2									2010	6.57			7.19	4.42	7.47	0.45	7.95	2.97	0.00	8.29	7.41					30				
WAJ Central Lab		26-Jul-02		Well 2																														
WAJ Central Lab		17-Aug-02		Combined									925	6.75			4.85	2.40	1.56	0.08	1.82	0.77	0.00	6.15	17.78					<2		<0.05	0.02	
WAJ Central Lab		17-Aug-02		Combined																											<2			
WAJ Central Lab		17-Aug-02		Combined																														
WAJ Central Lab		20-Aug-02		Well 1									1525	6.88			6.34	3.32	5.00	0.24	5.71	2.20	0.00	7.01	11.27									
WAJ Central Lab		20-Aug-02		Combined									945	6.96			5.29	2.31	1.79	0.09	1.89	0.80	0.00	6.35	15.00							0.07	0.04	
WAJ Central Lab		20-Aug-02		Well 1																														
WAJ Central Lab		20-Aug-02		Combined																														
WAJ Irbid Lab	53	23-Sep-02	349 L	Combined								0.500	886	7.25																	<1.1	<0.1	0.13	
WAJ Irbid Lab	121	23-Dec-02	72 L	Well 9								without	912	7.04																	<2		<0.1	
WAJ Irbid Lab Elec.		23-Dec-02		Well 9									912	7																	<2		<0.1	
WAJ Irbid Lab	46	24-Dec-02	82 L	Well 5								without	882	7.09																	<2			
WAJ Irbid Lab Elec.		24-Dec-02		Well 5									882	7.09																	<2			
WAJ Irbid Lab Elec.		14-Jan-03		Well 5									900	7.19	576		100	39	45	3.5	73	34	0	422	18.00	412					<2		<0.1	<0.02
WAJ Irbid Lab	48	27-Feb-03	164 S	Well 5								without	901	7.63	577		106.0	30.0	43.0	3.50	73.00	35.0	0.0	391.0	21.60	388				≥1600	<0.1	0.19		
WAJ Irbid Lab	122	27-Feb-03	167 L	Well 9								without	939	7.47	601		111.0	33.0	41.0	3.60	71.00	43.0	0.0	393.0	24.80	412.00				≥1600	<0.1	0.19		
WAJ Irbid Lab	131	27-Feb-03	162 S	Well 1								without	913	7.43	584		101.0	35.0	44.0	4.00	80.00	32.0	0.0	396.0	20.60	396.00				≥1600	0.300	0.40		
WAJ Irbid Lab Elec.		27-Feb-03		Well 3									903	7.46	578		106	28	44	4.6	81	53	0	339	28.30	378				≥1600	<0.1	0.7		
WAJ Irbid Lab Elec.		27-Feb-03		Well 8									901	7.59	577		103	33	43	3.5	72	25	0	406	19.70	394				<2		300	<0.1	0.5
WAJ Irbid Lab Elec.		27-Feb-03		Well 6									890	7.62	570		100	33	44	2.9	73	32	0	380	23.50	384				≥1600	0.3	0.21		
WAJ Irbid Lab	52	23-Apr-03	383 S	Combined								without	905	7.15	579		92.0	41.0	37.0	3.70	79.00	30.0	0.0	420.0	16.10	400.00		<2		2		0.150	0.05	
WAJ Central Lab		13-May-03		Combined									892	7.07			96.59	34.29	39.1	3.52	73.84	40.32	0	387.35	18.39	382				<2		<0.05	0.02	
WAJ Central Lab		13-May-03		Combined																											<2			
WAJ Central Lab		13-May-03		Combined									927	7.11			88.58	36.72	40.94	3.91	76.33	41.28	0	390.4	19.00	372				<2		<0.05	<0.02	
WAJ Central Lab		13-May-03		Combined																											<2			
WAJ Irbid Lab	2	15-Jul-03	410 S	Well 6								without	845	7.25	541		105.0	27.0	40.0	2.90	59.00	31.0	0.0	416.0	17.30	372.00				<2		<0.1		
WAJ Irbid Lab	123	15-Jul-03	411 S										922	7.21	590		106.0	32.0	48.0	3.70	72.00	38.0	0.0	433.0	16.90	394.00						<0.1		
WAJ Irbid Lab	163	15-Jul-03	409 S	Well 1									901	7.11	577		107.0	32.0	46.0	3.30	73.00	37.0	0.0	423.0	16.80	400.00						<0.1		
WAJ Irbid Lab Elec.		15-Jul-03		Well 9									922	7.21	590		106	32	48	0	72					394		<2		8		<0.1		
WAJ Irbid Lab Elec.		15-Jul-03		Well 6									845	7.25	541		105	27	40	2.9	59	31	0	416	17.30	372				<2		<0.1		
WAJ Irbid Lab	97	22-Jul-03	419 S	Well 3																														
WAJ Irbid Lab Elec.		22-Jul-03		Well 3																														
WAJ Irbid Lab	51	25-Jan-04	5925 S	Combined								0.200	874	7.25																	<1.1			
WAJ Irbid Lab	50	17-Feb-04	6146 S	Well 5								without	868	7.14											17.80						<2		<0.1	
WAJ Irbid Lab	101	17-Feb-04	6147 S	Combined									0.900	7.11											18.00						<1.1		<0.1	
WAJ Irbid Lab	100	14-Mar-04	6444 S	Combined									0.300	881	7.32																<1.1			
WAJ Central Lab		13-Apr-04		Well 5																									<2		130			
WAJ Irbid Lab	1	25-Apr-04	7055 S	Well 6								without	834	7.7	534		97.8	32.1	37.0	3.10	56.00	30.0	0.0	405.7	16.00	376.00				6		<0.1	0.08	
WAJ Irbid Lab	49	25-Apr-04	7054 S	Well 5									878	7.70	562		102.6	30.1	41.0	3.50	64.40	33.4	0.0	412.6	16.00	380.00				9		<0.1	0.70	
WAJ Irbid Lab	96	25-Apr-04	7053 S	Well 3								without	915	7.70	586		102.6	32.6	47.0	3.90	70.30	37.0	0.0	417.2	13.70	390.00						<0.1	0.07	
WAJ Irbid Lab	124	25-Apr-04	7056 S	Well 9									904	7.44	579		101.8	34.5	44.0	3.90	70.00	37.0	0.0	419.6	15.70	396.00						<0.1	0.49	
WAJ Irbid Lab	162	25-Apr-04	7052 S	Well 1								without	892	7.59	571		101.8	30.1	43.0	3.70	66.50	34.6	0.0	410.3	14.80	378.00				<2		<0.1	0.91	
WAJ Central Lab		13-Jun-04		Well 5																											17		50	
WAJ Irbid Lab	99	20-Jun-04	7880 S	Combined									889	7.22											18.10							<0.1		
WAJ Irbid Lab	98	22-Jun-04	7917 S	Combined									899	7.07	575		100.2	34.0	41.5	3.80	75.90	41.0	0.0	412.6	16.60	390.00						<0.1	0.10	

Table D-1

Table D-1 Tabaqet Fahel Wells Water Qu:																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						</
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Table D-1

APPENDIX E ECONOMIC VELOCITY IN FORCE MAINS

Hazen-Williams equation in metric units:

$$V = k C R^{0.63} S^{0.54}$$

Where V = velocity (m/s), C = friction factor, R = hydraulic radius (m), S = friction slope (m/m)

Substituting $V=Q/A$, $R=D/4$, $H_f=S L$, $k=0.85$

$$H_f = L [Q / (\pi k C)]^{1.8518} \cdot 4^{3.018519} / D^{4.8704}$$

where Q = flow (m³/s), A = pipe area (m²), H_f = friction headloss, D = diameter (m)

Evaluation of constants:

$$1/0.54 = 1.851851852$$

$$1.63/.54 = 3.018518519$$

$$2.63/.54 = 4.87037037$$

$$\pi \cdot k = 2.6703515$$

$$4^{3.0185} = 65.66428702$$

By substitution,

$$H_f = 65.664 L [Q / 2.67035 C]^{1.85185} / D^{4.8704}$$

where L = length (m)

$$\text{Total Cost} = C = u L + PWF \cdot u_{el} \cdot \text{hrs/yr} \cdot \text{Gamma} \cdot Q \cdot H_f / e$$

where

u = unit cost of pipe, JD/m length

PWF = present-worth factor, say 50 years at 6%

u_{el} = unit price of electricity, JD/kwh

hrs/yr = 8760 hours/year

Gamma = 9.81 gravity constant

e = pump efficiency, say 65%

$$\text{Pipe Cost } u = a D^b$$

where from regression analysis,

$$0.35740051$$

$$a = .503381 \cdot .71 \cdot 1000^{1.0098533} =$$

$$382.573662$$

$$b = 1.0098533$$

$$1.0098533$$

Derivative of cost with respect to diameter, for known values of Q and C:

$$dC/dD = 0 = 1.0098533 \cdot a \cdot D^{0.0098533} - 4.8704 \cdot PWF \cdot u_{el} \cdot \text{hrs/yr} \cdot \text{Gamma} \cdot Q \cdot 65.664 \cdot \text{cont'd} \\ \cdot [Q/2.67035 C]^{1.85185} / D^{5.8704} / e$$

Solving for D,

$$D^{[5.8704+0.0098533]} = \frac{(4.8704 / 1.0098533 \cdot a) \cdot PWF \cdot u_{el} \cdot \text{hrs/yr} \cdot \text{Gamma} \cdot Q \cdot \text{cont'd}}{65.664 [Q/2.67035 C]^{1.85185} / e}$$

Interest Rate	Useful Life	PWF
0.06	50	16.70757
0.06	20	12.15812
0.06	100	17.61460
0.04	50	22.34147
0.04	20	14.13394
0.04	100	25.48520
0.08	50	13.21216
0.08	20	10.60360
0.08	100	13.49386

Select trial values of the parameters:

$$u_{el} = 0.062 \text{ JD/kWh}$$

$$\text{hrs/yr} = 8760$$

$$\text{Gamma} = 9.81$$

$$e = 0.65$$

$$\text{exponent of } D = 5.88025$$

$$\text{reciprocal of exponent} = 0.170060797$$

$$2.67035^{1.85185} = 6.165102454$$

$$\text{exponent of } Q = 0.484987883$$

$$\text{exponent of } C = 0.314927086$$

$$D^{5.88025} = 18388.36456 \cdot Q^{2.85185} / C^{1.85185}$$

$$D \text{ (m)} = 5.311676269 \cdot Q^{.48498} / C^{.314927}$$

Q, m3/hr	Q, m3/s	D, m	D, mm	V, m/s	C	Diameter for 1.2 Max Day	Pk Vel, 1.2 MDF
50	0.0139	0.152	152	0.7664	110	161	0.81992
100	0.0278	0.213	213	0.7825	110	225	0.83716
200	0.0556	0.298	298	0.7990	110	315	0.85477
500	0.1389	0.464	464	0.8213	110	491	0.87861
1000	0.2778	0.649	649	0.8385	110	688	0.89708
2000	0.5556	0.909	909	0.8562	110	963	0.91595
5000	1.3889	1.418	1418	0.8801	110	1501	0.94150

Assume 1 constant-speed pump designed for maximum daily flow; look at effect on pipe diameter

Qpk/Qavg	Hrs/day	Hpk/Havg	Qpk Hpk dt	Power/base	Diam/base	PkVel/base	
1	24	1	24	1.00	1	1	<--"base"
1.2	20	1.402	33.64	1.40	1.059	1.07	
1.5	16	2.119	50.85	2.12	1.136	1.16	
2	12	3.610	86.63	3.61	1.244	1.29	

Domestic power tariff:

Monthly kWh		Price	Incr.	Cum.	Avg Price
from	to	JD/kWh	Cost, JD	Cost, JD	JD/kWh
1	160	0.031	4.960	4.960	0.031
161	300	0.057	7.980	12.940	0.043
301	500	0.065	13.000	25.940	0.052
501	1065	0.080	45.200	71.140	0.067

Monthly kWh		Price	Incr.	Cum.	Avg Price
from	to	JD/kWh	Cost, JD	Cost, JD	JD/kWh
1	160	0.031	4.960	4.960	0.031
161	300	0.057	17.100	17.100	0.057
301	500	0.065	32.500	32.500	0.065
501	1065	0.080	85.200	85.200	0.080

For now,
use uel=0.04 JD/kWh

16.708 PWF		Year	PW	Year	PW
Year	PW				
1	1.0000	22	0.2942	44	0.0816
2	0.9434	23	0.2775	45	0.0770
3	0.8900	24	0.2618	46	0.0727
4	0.8396	25	0.2470	47	0.0685
5	0.7921	26	0.2330	48	0.0647
6	0.7473	27	0.2198	49	0.0610
7	0.7050	28	0.2074	50	0.0575
8	0.6651	29	0.1956		
9	0.6274	30	0.1846		
10	0.5919	31	0.1741		
11	0.5584	32	0.1643		
12	0.5268	33	0.1550		
13	0.4970	34	0.1462		
14	0.4688	35	0.1379		
15	0.4423	36	0.1301		
16	0.4173	37	0.1227		
17	0.3936	38	0.1158		
18	0.3714	39	0.1092		
19	0.3503	40	0.1031		
20	0.3305	41	0.0972		
21	0.3118	42	0.0917		
		43	0.0865		

Assume 1 constant-speed pump operating intermittently at a maximum daily rate of 1.2 * average Q

For a given pipe diameter, the "optimal average flow" is then:

$$D(\text{mm}) = 4710.3 * (Q_{pk}, \text{m}^3/\text{hr} / (3600 * 1.2))^{0.48498} * (1.2)^{0.17006} / C^{0.314927}$$

Using C=110,

$$D(\text{mm}) = 21.51007 Q_{pk}^{0.48498}$$

$$\text{reciprocal of the exponent } 0.48498 = 2.061907183$$

$$19.07^{2.0619} = 559.4789018$$

or for a given diameter D(mm), the "optimal peak flow" is then

$$Q_{pk} = D_{mm}^{2.061907} / 436.708$$

Diameter mm	Qpk		Area m2	Peak Vel m/s	Qavg		Avg. Vel m/s
	m3/hr	m3/s			m3/hr	m3/s	
100	23.8	0.0066	0.0079	0.841	19.8	0.0055	0.701
150	54.8	0.0152	0.0177	0.862	45.7	0.0127	0.718
200	99.2	0.0276	0.0314	0.878	82.7	0.0230	0.731
250	157.2	0.0437	0.0491	0.890	131.0	0.0364	0.741
300	229.0	0.0636	0.0707	0.900	190.8	0.0530	0.750
400	414.4	0.1151	0.1257	0.916	345.3	0.0959	0.763
500	656.5	0.1824	0.1963	0.929	547.1	0.1520	0.774
600	956.1	0.2656	0.2827	0.939	796.8	0.2213	0.783
700	1313.8	0.3650	0.3848	0.948	1094.9	0.3041	0.790
800	1730.3	0.4806	0.5027	0.956	1441.9	0.4005	0.797
900	2205.9	0.6128	0.6362	0.963	1838.3	0.5106	0.803
1000	2741.2	0.7614	0.7854	0.969	2284.3	0.6345	0.808
1100	3336.5	0.9268	0.9503	0.975	2780.4	0.7723	0.813
1200	3992.1	1.1089	1.1310	0.981	3326.8	0.9241	0.817

Find the range of flows over which a given diameter is the optimal choice:

Pipe Cost= $a D^b = 382.5736619 * (D/1000)^{1.0098533}$

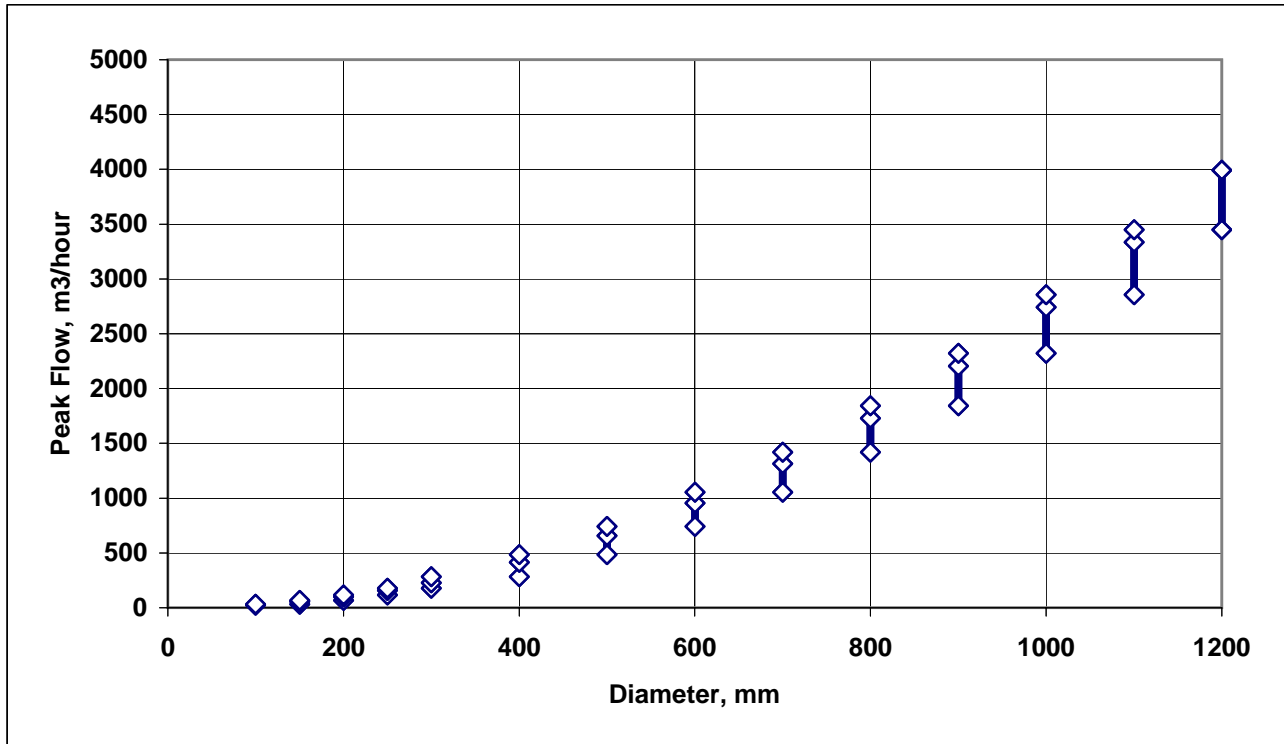
PW power cost= $PWF * u_{el} * \text{hrs/yr} * \Gamma * Q_{avg}/3600 * S_f \text{ avg} * 1.4 / e$
 $53.25867159 Q_{avg}, \text{m}^3/\text{hr} * S_f \text{ avg}$

Friction slope= $[Q_{avg} / (3600 \pi k C)]^{1.8518} * 4^{3.018519} / (D/1000)^{4.8704}$

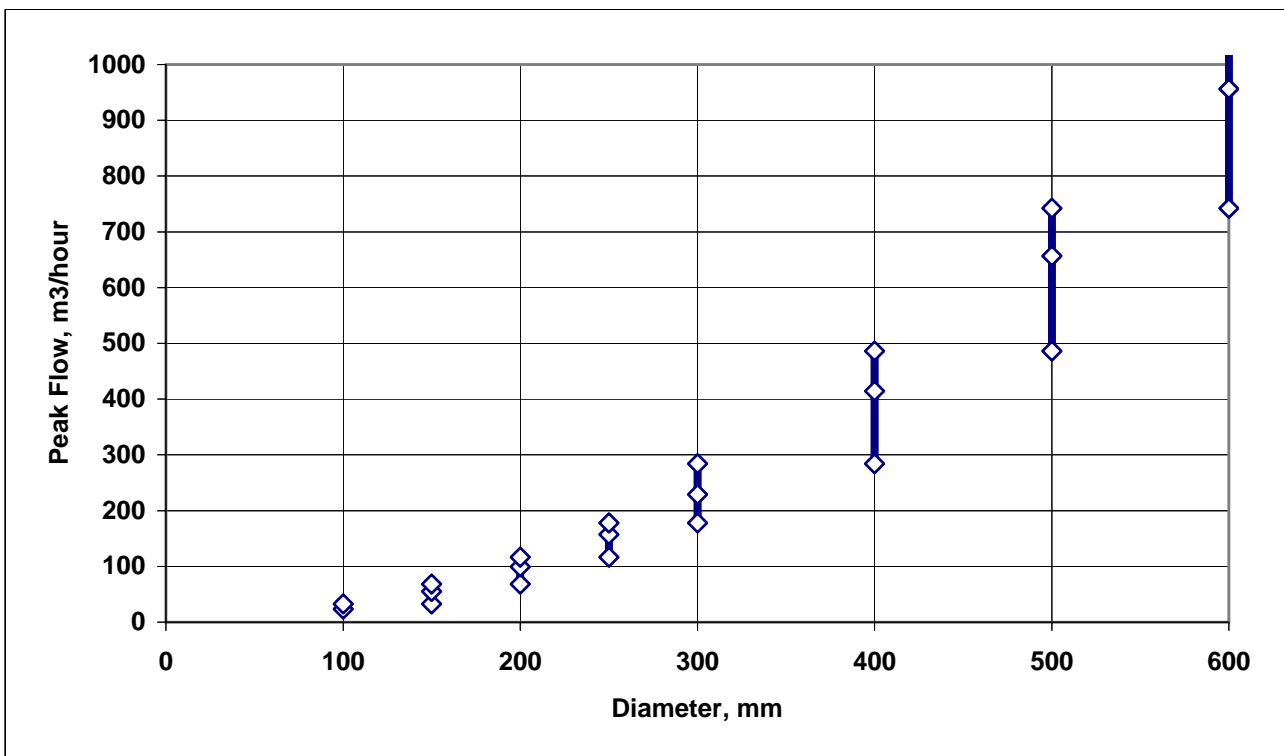
$[Q_{avg} / 1,057,459.19]^{1.8518} * 65.664287 / (D/1000)^{4.8704}$
 $1/2.8518 = 0.3506 \quad 2.851851852$

Condition	Diameter mm	Qpk m ³ /hr	Qavg m ³ /hr	Sf avg m/m	PW Power JD	Pipe Cost JD	Total JD
Optimal	100	23.8	19.81	0.00857	9.046	37.399	46.445
Maximum	100	32.4	27.04	0.01526	21.974	37.399	59.373
Minimum	150	32.4	27.04	0.00212	3.050	56.323	59.373
Optimal	150	54.8	45.70	0.00560	13.624	56.323	69.947
Maximum	150	68.0	56.70	0.00834	25.193	56.323	81.517
Minimum	200	68.0	56.70	0.00206	6.206	75.311	81.517
Optimal	200	99.2	82.71	0.00414	18.217	75.311	93.528
Maximum	200	116.4	97.03	0.00556	28.723	75.311	104.034
Minimum	250	116.4	97.03	0.00187	9.688	94.346	104.034
Optimal	250	157.2	131.03	0.00327	22.821	94.346	117.167
Maximum	250	177.8	148.17	0.00411	32.408	94.346	126.754
Minimum	300	177.8	148.17	0.00169	13.336	113.419	126.754
Optimal	300	229.0	190.82	0.00270	27.435	113.419	140.854
Maximum	300	284.1	236.72	0.00402	50.732	113.419	164.150
Minimum	400	284.1	236.72	0.00099	12.496	151.654	164.150
Optimal	400	414.4	345.34	0.00199	36.684	151.654	188.338
Maximum	400	486.1	405.12	0.00268	57.840	151.654	209.494
Minimum	500	486.1	405.12	0.00090	19.509	189.985	209.494
Optimal	500	656.5	547.09	0.00158	45.956	189.985	235.941
Maximum	500	742.4	618.68	0.00198	65.261	189.985	255.246
Minimum	600	742.4	618.68	0.00081	26.854	228.392	255.246
Optimal	600	956.1	796.76	0.00130	55.247	228.392	283.639
Maximum	600	1053.5	877.94	0.00156	72.861	228.392	301.253
Minimum	700	1053.5	877.94	0.00074	34.390	266.862	301.253
Optimal	700	1313.8	1094.87	0.00111	64.553	266.862	331.415
Maximum	700	1420.0	1183.37	0.00128	80.573	266.862	347.435
Minimum	800	1420.0	1183.37	0.00067	42.048	305.387	347.435
Optimal	800	1730.3	1441.91	0.00096	73.873	305.387	379.259
Maximum	800	1842.4	1535.35	0.00108	88.360	305.387	393.747
Minimum	900	1842.4	1535.35	0.00061	49.788	343.959	393.747
Optimal	900	2205.9	1838.27	0.00085	83.204	343.959	427.163
Maximum	900	2321.1	1934.26	0.00093	96.202	343.959	440.161
Minimum	1000	2321.1	1934.26	0.00056	57.588	382.574	440.161
Optimal	1000	2741.2	2284.32	0.00076	92.545	382.574	475.118
Maximum	1000	2856.5	2380.41	0.00082	104.084	382.574	486.658
Minimum	1100	2856.5	2380.41	0.00052	65.432	421.226	486.658
Optimal	1100	3336.5	2780.38	0.00069	101.895	421.226	523.122
Maximum	1100	3448.9	2874.09	0.00073	111.998	421.226	533.224
Minimum	1200	3448.9	2874.09	0.00048	73.310	459.914	533.224
Optimal	1200	3992.1	3326.76	0.00063	111.254	459.914	571.168

Maximum Daily Flow: Optimal Range for a Given Diameter



A. BIG PIPES



B. little pipes

Appendix F

Energy Management Considerations

F.1 General

The purpose of this section is to summarize the following:

- The cost of electricity in Jordan, compared to the subsidized prices paid by WAJ, and the expected future cost and tariff structure for electricity;
- The options for operation of pumps and reservoir storage, if an un-subsidized tariff structure was applied to WAJ, that would affect the design and cost of the transmission system; and
- An investigation into the possible use of variable-frequency drives on deep-well pumps, to reduce power consumption.

F.2 Cost of Electricity in Jordan

A series of interviews were conducted to obtain a perspective on the existing and future prices for electricity in Jordan. Of these, the most comprehensive interview was with the Director General of the newly-created Electricity Sector Regulatory Commission; the results of this interview are described below. This agency is responsible for over-seeing the prices charged by the separate companies that are now responsible for the generation, transmission and distribution of electricity within Jordan. For example, 5 power companies are involved in the northern governorates, of which the Irbid Power Distribution Co. is responsible for billing of customers in the four northern governorates.

At present, a large portion of the power generation in Jordan is centered in Aqaba, where five generators (each 150 MW) utilize a natural-gas transmission line from Egypt. This transmission line is currently being extended to northern Jordan, and hence to Syria and perhaps Turkey. Within northern Jordan, natural gas from the new transmission line will be used for power generation locally. By using Egyptian natural gas, Jordan is not directly affected by the price of petroleum, which recently increased to more than \$50/barrel.

The various prices and tariff structures applicable to WAJ are summarized in **Table F-1**. At present, WAJ consumes about 15% to 17% of the power production in Jordan, and pays a subsidized price of 38 fils/kWh; this compares to an un-subsidized average cost of 52 fils/kWh and the subsidized price paid by farmers for irrigation wells of 28 fils/kWh. As a result of payments for the new natural-gas pipeline and other power facilities, the price of electricity paid by WAJ is expected to increase to 45 fils/kWh within 10 years. This is assumed to be a subsidized price, since it amounts to only an 18% increase over the 10 years. The unsubsidized price is assumed to increase (in proportion to WAJ's price) from 52 to 62 fils/kWh. This price of 62 fils/kWh has been used in applying the analysis for economical velocity in pipelines (in Appendix E), as well as in this section. The tariff structure for medium-sized industry is considered to be un-subsidized and applicable to WAJ if the WAJ subsidy were removed. Medium-sized industries pay a demand charge (fils/kW/month) during the 3 hours of peak demand each day (19:00-22:00 in summer, 17:00-20:00 in winter), and separate prices for day-time and night-time energy use.

Table F-1 Summary of Data on Electricity Prices and Assumed Pump Operations

Item	Total prices		Units
A. Information from Electricity Sector Regulatory Commission			
Unsubsidized energy cost on average	52		fi/s/kwh
Price paid by WAJ at present	38		fi/s/kwh
Price paid by WAJ in 10 years	45		fi/s/kwh
Assumed unsubsidized cost in 10 years[1]	62		fi/s/kwh
[1] Note: 62 fi/s/kWh = 52 * 45/38			
Item	Current	in 10 years	Units
B. Un-subsidized Prices paid by Medium-Sized Industries			
Peak-period demand charge	3.05	3.61	JD/kw/mo
Day-time energy	36.00	42.63	fi/s/kwh
Night-time energy	27.00	31.97	fi/s/kwh

Item		Value	Units
C. Typical well-pump characteristics and operation			
Head		200	m
Flow		50	m3/hr
Efficiency, wire to water		55%	%
Power requirements		49.5	KW
% of time in operation		70%	%
Day-time operating hours			
summer 7:00-22:00		15	hrs/day
winter 7:00-20:00		13	hrs/day
Night-time operating hours, constant supply			
summer 22:00-7:00		1.8	hrs/day
winter 20:00-7:00		3.8	hrs/day
Night-time operating hours, seasonal demands USE:			
summer		2.8	hrs/day
winter		2.8	hrs/day
Assume 6 months winter, 6 months summer			
summer daytime		2737.5	hrs/year
winter daytime		2372.5	hrs/year
year nighttime		1022	hrs/year

F.3 Options for Operation of Pumps and Distribution Reservoirs

For a typical deep-well pump, the assumed operating conditions over a typical year are shown in Part C of **Table F-1**. These values include the flow, head, efficiency, and operating hours during the summer and winter, and night-time and day-time. These values have been used to compare options for design and operation of the transmission system, of which the results for two options are shown in **Table F-2**. The first option is the existing method of operation, in which pumps are operated throughout the day; the second option is to shut off the pumps during the 3 hours per day of peak power demand, so as to eliminate the power demand charge. Option 2 would reduce the power bill by 19% compared to Option 1. Much of this saving could be made at a relatively low capital cost, since the maximum-daily-demand factor of 1.20 would cover the additional capacity of $24/21 = 1.14$ needed on days of average demand at the design year. The demand charge might only be incurred on 2 or 3 months out of the year, and only toward the end of the planning period when the water demands are approaching the design limit. The additional volume required in the distribution storage reservoir, of 3 hours flow volume, would be at most a small additional

cost; in most cases, the additional volume would be absorbed in the round-off to a standard tank size.

Table F-2 Options for Pump Operations

Item			Price[1]	kWh/yr	Cost, JD/yr
Option 1. Existing 24-hour operations					
Energy	summer	daytime	42.63	135,631	5,782
	winter	daytime	42.63	117,547	5,011
	year	nighttime	31.97	50,635	1,619
Demand	annual		3.61		2,147
Totals				303,813	14,560
Average cost, fils/kwh			47.92		
Item			Price	kWh/yr	Cost, JD/yr
Option 2. No Pumping on Peak Hours (3 hrs/day)					
Energy	daytime		42.63	198,925	8,480
	nighttime		31.97	104,888	3,354
Demand	annual		3.61		0
Total				303,813	11,834
Average cost, fils/kwh; savings			38.95		2,726

Other options might also be considered, such as pumping water only at night. The structure of the power tariff can make this option economical, for example in some cities in the USA such as Albuquerque, New Mexico. However, for the tariff structure in Jordan, night-time pumping would not be economical: the required increase in pumping capacity of the wells and capacity of pipelines, and the sizable increase in reservoir storage, would cause a significant increase in the capital cost of the transmission system. Preliminary estimates indicate that the potential savings in power cost would not offset the increase in capital cost.

F.4 Variable-Frequency Drives on Well Pumps

The submersible pumps on the deep wells in the NG WA system could be driven by variable-frequency drives (VFDs), as a means to reduce power consumption and increase the life of the pumps. A preliminary investigation has been made, but the results are inconclusive because there is no current reliable data on the hydraulic heads of interest: the static groundwater level; the dynamic water level when the well is in operation; and the delivery hydraulic gradeline at each well. However, the deep wells are the largest category of power consumption within the NGWA system, and several problems are evident. Within WAJ, all new well pumps in Jordan are purchased and installed under a centralized maintenance and procurement department, which maintains a stock of pre-purchased pumps. When an existing pump fails, the department works with the local water engineer to find the best match between the pumps in stock and the service conditions expected in the field. In some cases, the best match is not very good; OMS has reported verbally that in some cases the apparent pumping efficiency is only 35% and new pumps are wearing out after 1 or 2 years (rather than 10 years or longer). The cause of the inefficiency and short life is difficult to identify, because in many cases there is no flow meter or pressure gauge on the well pump discharge, and there is no reliable way to estimate the dynamic water level in the well. In the current study, an attempt to find the dynamic water levels on the 9 wells in the Wadi Al Arab system was unsuccessful at all 9 wells, usually because the plastic tubes inserted in the wells are plugged or will not pass the tape measure and water level detector.

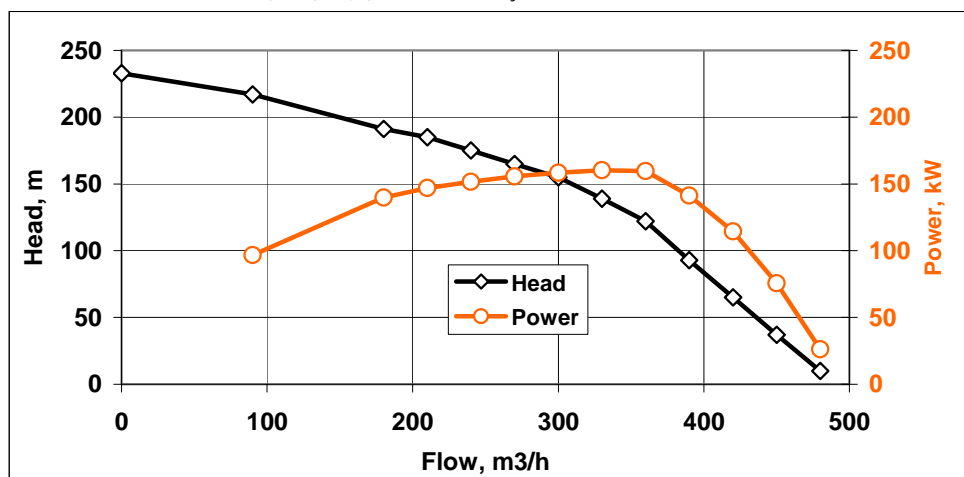
The potential savings in electricity by installing a VFD have been estimated for ten of the well pumps. As an illustration of the analysis, the pumps installed in the Wadi Al Arab well field, at Well Nos 1, 4 and 5 have been selected. All three of these wells contain the same pump, rated at a flow of 300 m³/hour and a head of 150 m; the pump is a Jet Model SG10C containing 5 impellers in series. The pump curve, brake horsepower curve, and efficiency curve are shown in Table F-3.

Table F-3 Wadi Al Arab Well Nos 1, 4 & 5: pump characteristics

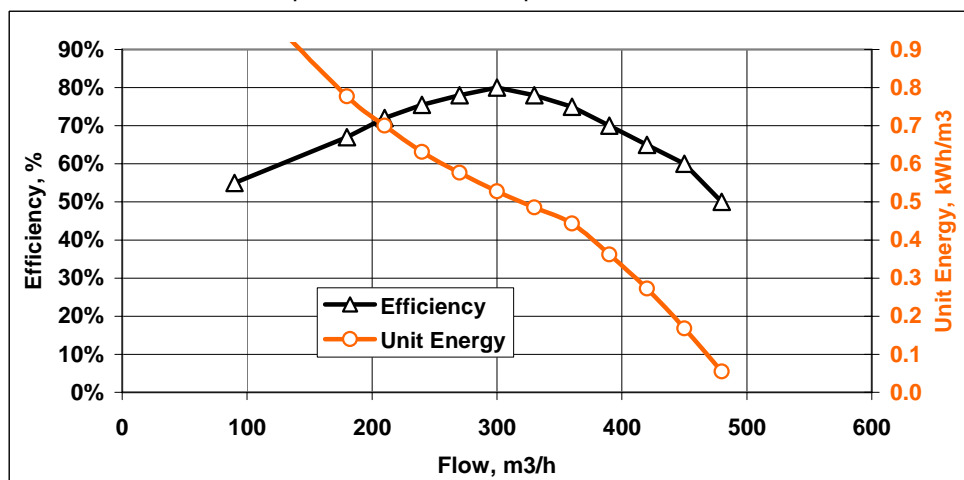
Flow m ³ /h	Head m	Eff. %	Power kW*	Energy kWh/m ³
0	233			
90	217	55.0%	96.8	1.08
180	191	67.0%	139.8	0.78
210	185	72.0%	147.0	0.70
240	175	75.5%	151.6	0.63
270	165	78.0%	155.6	0.58
300	155	80.0%	158.4	0.53
330	139	78.0%	160.3	0.49
360	122	75.0%	159.6	0.44
390	93	70.0%	141.2	0.36
420	65	65.0%	114.5	0.27
450	37	60.0%	75.6	0.17
480	10	50.0%	26.2	0.05

<---Best Efficiency Point

*Note: KW = 9.81 Q*H/e, for Q(m³/s), H(m) and e=efficiency



Pump Curve and Brake Horsepower Curve



Efficiency Curve and Unit Energy Curve

At the best-efficiency point of the pump, the head is 150m, which greatly exceeds the estimated head required of 45m at Wadi Al Arab Nos. 1 and 4, and 69m at Wadi Al Arab No. 5. Two alternatives for operation of these pumps have been examined:

1. Alternative 1: fixed-speed pump, with excess head dissipated across a throttling valve on the discharge line from the well
2. Alternative 2: variable-frequency drive installed on the power cable connected to the well pump, with the speed of the well pump adjusted to produce the design flow from the well. Under variable-speed operation, the head from a pump varies with the square of the speed, while the flow is linearly proportional to the speed.

The computations for these two alternatives, under a range of flow and head conditions, are shown in **Table F-4**, and the results are plotted in **Figure F-1**.

From **Figure F-1**, the savings in electricity from VFD operation (Alternative 2) is estimated at 65% for Wadi Al Arab Well Nos. 1 and 4, and at 51% for Wadi Al Arab No. 5. At the best-efficiency point of these pumps, the annual power cost would be about 88,000 JD for each of the three wells. The annual power savings for VFD operation would be 161,000 JD for the three wells, while the cost of a VFD would be roughly 10,000 JD for each well or 30,000 JD for the 3 wells. Thus, the cost of the VFD in this case would be repaid within 2 or 3 months by the power savings.

For the 10 well pumps that have been examined, the savings in energy is summarized in **Table F-5**. The savings range from about 1% to 66% of the energy consumed under fixed-speed throttled-flow operation. From these results, it is concluded that Variable Frequency Drive should be considered as an alternative when the proposed rehabilitation of the mechanical/electrical/instrumentation facilities at wells is undertaken.

Table F-4 Fixed-Speed Versus Variable-Speed Operation of Well Pumps

Alt. 1: Fixed Speed Pump					Alt. 2: Variable Frequency Drive				Savings	Energy
Target Flow m ³ /h	Pump Head m	System Head m	Head Diss'p'd m	Unit Energy kWh/m ³	Motor Speed % full spd	Flow at full spd m ³ /hr	Power kW	Unit Energy kWh/m ³	in Unit Energy kWh/m ³	Savings % of Alt. 1
90	217	48	169	1.075	50.00%	180	17.5	0.194	0.881	81.9%
90	217	34	183	1.075	42.86%	210	11.6	0.129	0.947	88.0%
90	217	25	192	1.075	37.50%	240	8.0	0.089	0.986	91.7%
90	217	18	199	1.075	33.33%	270	5.8	0.064	1.011	94.0%
90	217	14	203	1.075	30.00%	300	4.3	0.048	1.028	95.6%
90	217	10	207	1.075	27.27%	330	3.3	0.036	1.039	96.6%
90	217	8	209	1.075	25.00%	360	2.5	0.028	1.047	97.4%
90	217	5	212	1.075	23.08%	390	1.7	0.019	1.056	98.2%
90	217	3	214	1.075	21.43%	420	1.1	0.013	1.063	98.8%
90	217	1	216	1.075	20.00%	450	0.6	0.007	1.068	99.4%
90	217	0	217	1.075	18.75%	480	0.2	0.002	1.073	99.8%
180	191	136	55	0.777	85.71%	210	92.6	0.514	0.262	33.8%
180	191	98	93	0.777	75.00%	240	64.0	0.355	0.422	54.3%
180	191	73	118	0.777	66.67%	270	46.1	0.256	0.521	67.0%
180	191	56	135	0.777	60.00%	300	34.2	0.190	0.587	75.5%
180	191	41	150	0.777	54.55%	330	26.0	0.144	0.632	81.4%
180	191	31	161	0.777	50.00%	360	19.9	0.111	0.666	85.7%
180	191	20	171	0.777	46.15%	390	13.9	0.077	0.700	90.1%
180	191	12	179	0.777	42.86%	420	9.0	0.050	0.727	93.6%
180	191	6	185	0.777	40.00%	450	4.8	0.027	0.750	96.5%
180	191	1	190	0.777	37.50%	480	1.4	0.008	0.769	99.0%
210	185	134	51	0.700	87.50%	240	101.6	0.484	0.217	30.9%
210	185	100	85	0.700	77.78%	270	73.2	0.349	0.351	50.2%
210	185	76	109	0.700	70.00%	300	54.3	0.259	0.441	63.1%
210	185	56	129	0.700	63.64%	330	41.3	0.197	0.504	71.9%
210	185	42	143	0.700	58.33%	360	31.7	0.151	0.549	78.5%
210	185	27	158	0.700	53.85%	390	22.0	0.105	0.595	85.0%
210	185	16	169	0.700	50.00%	420	14.3	0.068	0.632	90.3%
210	185	8	177	0.700	46.67%	450	7.7	0.037	0.664	94.8%
210	185	2	183	0.700	43.75%	480	2.2	0.010	0.690	98.5%
240	175	130	45	0.632	88.89%	270	109.3	0.455	0.176	27.9%
240	175	99	76	0.632	80.00%	300	81.1	0.338	0.294	46.5%
240	175	74	101	0.632	72.73%	330	61.6	0.257	0.375	59.3%
240	175	54	121	0.632	66.67%	360	47.3	0.197	0.435	68.8%
240	175	35	140	0.632	61.54%	390	32.9	0.137	0.495	78.3%
240	175	21	154	0.632	57.14%	420	21.4	0.089	0.543	85.9%
240	175	11	164	0.632	53.33%	450	11.5	0.048	0.584	92.4%
240	175	3	173	0.632	50.00%	480	3.3	0.014	0.618	97.8%
270	165	126	39	0.576	90.00%	300	115.5	0.428	0.149	25.8%
270	165	93	72	0.576	81.82%	330	87.8	0.325	0.251	43.6%
270	165	69	96	0.576	75.00%	360	67.3	0.249	0.327	56.7%
270	165	45	120	0.576	69.23%	390	46.9	0.174	0.403	69.9%
270	165	27	138	0.576	64.29%	420	30.4	0.113	0.464	80.5%
270	165	13	152	0.576	60.00%	450	16.3	0.060	0.516	89.5%
270	165	3	162	0.576	56.25%	480	4.7	0.017	0.559	97.0%
300	155	115	40	0.528	90.91%	330	120.4	0.401	0.127	24.0%
300	155	85	70	0.528	83.33%	360	92.3	0.308	0.220	41.7%
300	155	55	100	0.528	76.92%	390	64.3	0.214	0.314	59.4%
300	155	33	122	0.528	71.43%	420	41.7	0.139	0.389	73.7%
300	155	16	139	0.528	66.67%	450	22.4	0.075	0.453	85.9%
300	155	4	151	0.528	62.50%	480	6.4	0.021	0.507	96.0%
330	139	103	36	0.486	91.67%	360	122.9	0.372	0.113	23.3%
330	139	67	72	0.486	84.62%	390	85.5	0.259	0.226	46.6%
330	139	40	99	0.486	78.57%	420	55.5	0.168	0.317	65.4%
330	139	20	119	0.486	73.33%	450	29.8	0.090	0.395	81.4%
330	139	5	134	0.486	68.75%	480	8.5	0.026	0.460	94.7%
360	122	79	43	0.443	92.31%	390	111.1	0.308	0.135	30.4%
360	122	48	74	0.443	85.71%	420	72.1	0.200	0.243	54.8%
360	122	24	98	0.443	80.00%	450	38.7	0.108	0.336	75.7%
360	122	6	116	0.443	75.00%	480	11.0	0.031	0.413	93.1%
390	93	56	37	0.362	92.86%	420	91.6	0.235	0.127	35.1%
390	93	28	65	0.362	86.67%	450	49.2	0.126	0.236	65.1%
390	93	7	86	0.362	81.25%	480	14.0	0.036	0.326	90.1%
420	65	32	33	0.273	93.33%	450	61.5	0.146	0.126	46.3%
420	65	8	57	0.273	87.50%	480	17.5	0.042	0.231	84.7%

Figure F-1 Energy Savings from VFD Operation of Well Pumps

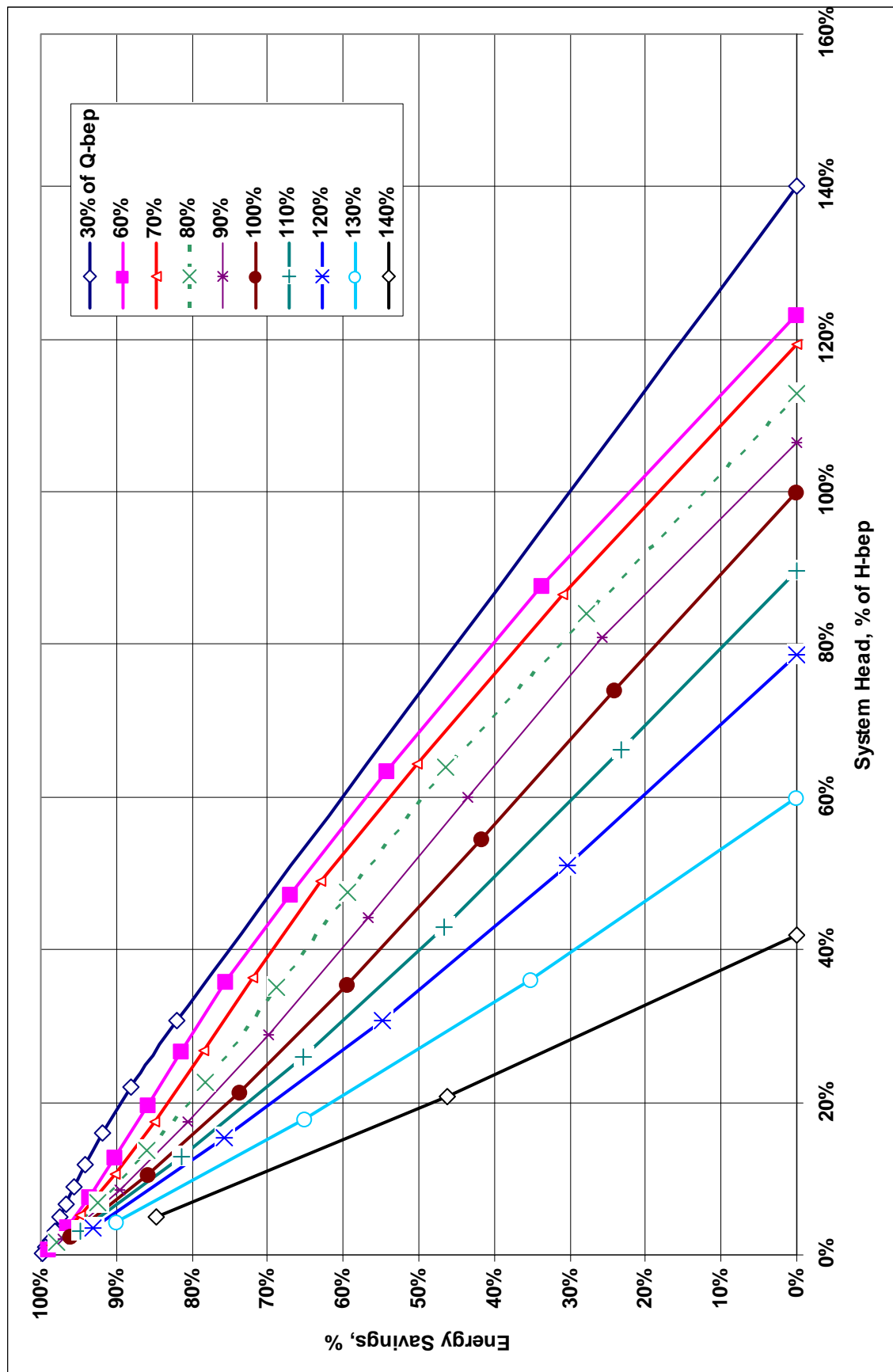


Table F-5 Summary of Estimated Savings in Energy from Variable-Frequency Drive Operation

Well Pump	Rated Flow, m ³ /hour	Rated Head, m	Pump Manufacturer	Pump Model	Installation Date	No. of Impellers	System Head, m	Head, % of H-bep	% Energy Savings
Aqeb 101B	70	250	Jet	SG8B	11/8/2003	13	247	99%	1%
Aqeb 110	100	300	Van San	VSP0833	5/8/2004	18	270	90%	11%
Aqeb 114	100	300	Jet	SG8D	4/3/2002	16	274	91%	12%
Wadi Arab 1	300	150	Jet	SG10C	11/1/2003	5A	45	30%	65%
Wadi Arab 4	300	150	Jet	SG10C	2/15/2002	5	45	30%	66%
Wadi Arab 5	300	150	Jet	SG10C	3/23/2004	5	69	46%	51%
Wadi Arab 8	100	120	Jet	SG8D	11/27/2002	7B	69	58%	38%
Wadi Arab 9	90	200	Vogel	87TV10SN	4/5/2003	10	81	41%	54%
Zatary 3A	70	250	Jet	SG8B	8/13/2003	13	195	78%	22%
Zatary 4	70	250	Caprari	E8S48US	6/21/2004	12	184	73%	24%